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PHILOSOPHICAL

TRANSACTIONS

OF THE

ROYAL SOCIETY

OF

LONDON.

FOR THE YEAR MDCCCXLII.

PART I.

LONDON:

PRINTED BY RICHARD AND JOHN E. TAYLOR, RED LION COURT, FLEET STREET.

MDCCCXLII.

ADVERTISEMENT.

The Committee appointed by the *Royal Society* to direct the publication of the *Philosophical Transactions,* take this opportunity to acquaint the Public, that it fully appears, as well from the Council-books and Journals of the Society, as from repeated declarations which have been made in several former *Transactions,* that the printing of them was always, from time to time, the single act of the respective Secretaries till the Forty-seventh Volume; the Society, as a Body, never interesting themselves any further in their publication, than by occasionally recommending the revival of them to some of their Secretaries, when, from the particular circumstances of their affairs, the *Transactions* had happened for any length of time to be intermitted. And this seems principally to have been done with a view to satisfy the Public, that their usual meetings were then continued, for the improvement of knowledge, and benefit of mankind, the great ends of their first institution by the Royal Charters, and which they have ever since steadily pursued.

But the Society being of late years greatly enlarged, and their communications more numerous, it was thought advisable that a Committee of their members should be appointed, to reconsider the papers read before them, and select out of them such as they should judge most proper for publication in the future *Transactions*; which was accordingly done upon the 26th of March 1752. And the grounds of their choice are, and will continue to be, the importance and singularity of the subjects, or the advantageous manner of treating them; without pretending to answer for the certainty of the facts, or propriety of the reasonings, contained in the several papers so published, which must still rest on the credit or judgement of their respective authors.

It is likewise necessary on this occasion to remark, that it is an established rule of the Society, to which they will always adhere, never to give their opinion, as a Body,

upon any subject, either of Nature or Art, that comes before them. And therefore the thanks, which are frequently proposed from the Chair, to be given to the authors of such papers as are read at their accustomed meetings, or to the persons through whose hands they received them, are to be considered in no other light than as a matter of civility, in return for the respect shown to the Society by those communications. The like also is to be said with regard to the several projects, inventions, and curiosities of various kinds, which are often exhibited to the Society; the authors whereof, or those who exhibit them, frequently take the liberty to report and even to certify in the public newspapers, that they have met with the highest applause and approbation. And therefore it is hoped that no regard will hereafter be paid to such reports and public notices; which in some instances have been too lightly credited, to the dishonour of the Society.

A List of Public Institutions and Individuals, entitled to receive a copy of the Philosophical Transactions of each year, on making application for the same directly or through their respective agents, within five years of the date of publication.

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The Observatory at Wilna.
Professor Bessel, of Königsberg.
The Dépôt de la Marine, Paris.
The Bowden College, United States.
The Waterville College, United States.

ROYAL MEDALS.

HER MAJESTY QUEEN VICTORIA, in restoring the Foundation of the Royal Medals, has been graciously pleased to approve of the following regulations for the award of them:

That the Royal Medals be given for such papers only as have been presented to the Royal Society, and inserted in their Transactions.

That the triennial Cycle of subjects be the same as that hitherto in operation: viz.

1. Astronomy; Physiology, including the Natural History of Organized Beings.
2. Physics; Geology or Mineralogy.
3. Mathematics; Chemistry.

That, in case no paper, coming within these stipulations, should be considered deserving of the Royal Medal, in any given year, the Council have the power of awarding such Medal to the author of any other paper on either of the several subjects forming the Cycle, that may have been presented to the Society and inserted in their Transactions; preference being given to the subjects of the year immediately preceding: the award being, in such case, subject to the approbation of Her Majesty.

The Council propose to give one of the Royal Medals in the year 1842 for the most important unpublished paper in Astronomy, communicated to the Royal Society for insertion in their Transactions after the termination of the Session in June 1839, and prior to the termination of the Session in June 1842.

The Council propose also to give one of the Royal Medals in the year 1842 for the most important unpublished paper in Physiology, including the Natural History of

Organized Beings, communicated to the Royal Society for insertion in their Transactions after the termination of the Session in June 1839, and prior to the termination of the Session in June 1842.

The Council propose to give one of the Royal Medals in the year 1843 for the most important unpublished paper in Physics, communicated to the Royal Society for insertion in their Transactions after the termination of the Session in June 1840, and prior to the termination of the Session in June 1843.

The Council propose also to give one of the Royal Medals in the year 1843 for the most important unpublished paper in Geology or Mineralogy, communicated to the Royal Society for insertion in their Transactions after the termination of the Session in June 1840, and prior to the termination of the Session in June 1843.

The Council propose to give one of the Royal Medals in the year 1844 for the most important unpublished paper in Mathematics, communicated to the Royal Society for insertion in their Transactions after the termination of the Session in June 1841, and prior to the termination of the Session in June 1844.

The Council propose also to give one of the Royal Medals in the year 1844 for the most important unpublished paper in Chemistry, communicated to the Royal Society for insertion in their Transactions after the termination of the Session in June 1841, and prior to the termination of the Session in June 1844.

The Council propose to give one of the Royal Medals in the year 1845 for the most important unpublished paper in Astronomy, communicated to the Royal Society for insertion in their Transactions after the termination of the Session in June 1842, and prior to the termination of the Session in June 1845.

The Council propose also to give one of the Royal Medals in the year 1845 for the most important unpublished paper in Physiology, including the Natural History of Organized Beings, communicated to the Royal Society for insertion in their Transactions after the termination of the Session in June 1842, and prior to the termination of the Session in June 1845.

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The Copley Medal to Professor James MacCullagh, of Trinity College Dublin, for his researches connected with the "Wave-Theory of Light," contained in the Transactions of the Royal Irish Academy.

The Rumford Medal to William Henry Fox Talbot, Esq., F.R.S., for his discoveries and improvements in Photography.

The Royal Medal, in the department of Physiology, to William Bowman, Esq., F.R.S., for his Paper "On the Structure and Use of the Malpighian Bodies of the Kidney, with Observations on the Circulation through that gland," published in the Philosophical Transactions for 1842.

The other Royal Medal, not having been awarded in the department of Astronomy, was awarded in that of Chemistry to John Frederic Daniell, Esq., Foreign Secretary of the Royal Society, for his "Letters on the Electrolysis of Secondary Compounds, and on Voltaic Combinations," published in the Transactions for 1840 and 1841.

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Meteorological Journal kept at the Apartments of the Royal Society, by order of the President and Council.

PHILOSOPHICAL TRANSACTIONS.

I. *On the Laws of the Rise and Fall of the Tide in the River Thames.*

By G. B. Airy, *Esq., M.A., F.R.S., Astronomer Royal.*

Received July 3,—Read November 25, 1841.

In the winter of 1840–1841, an extensive series of observations of tides was made, in accordance with my suggestions, at Deptford Royal Victualling Yard. For these observations, as well as for those which follow (and which form more immediately the subject of this paper), I am indebted to Captain Shirreff, R.N., Captain Superintendent of the Royal Victualling Yard and Dock Yard at Deptford. By the kindness of this able officer, I was allowed to give such directions to the police constables on duty in the Victualling Yard as I thought necessary for my purpose; and by his continual superintendence of the observations, I was able to satisfy myself that they were conducted exactly as I desired, and were worthy of the fullest confidence. I cannot adequately express my sense of the attention which thus put me in possession of the data that I desired, and in the very form in which I desired them, without the smallest trouble to me in the whole transaction.

The mode of making the observations was the following. Under the direction of Captain Shirreff, a vertical scale of feet and inches was marked on the return of the wharf-wall adjoining to the principal landing-stairs of the Victualling Yard. The graduations increased in going downwards, the top of the wharf-wall being the zero. As the bottom of this return of the wall was sometimes dry at low water, a level line was carried to the extremity of the causeway at the bottom of the principal stairs, and another vertical scale (in continuation of the former) was measured there. Thus every observation of the surface of the water was a measure of its depression below the top of the wharf-wall. The times of the observations were in all cases the quarters of hours of mean solar time, as indicated by the striking of the clock of the Victualling Yard. It is proper to mention, that, in consequence of the extensive visibility of the signal-ball of the Royal Observatory (which is dropped at 1^h P.M. precisely), the public clocks in the neighbourhood of Greenwich are for the most part extremely well regulated; and I have therefore little doubt that the times of observation are pretty accurately those which they profess to be.

The object of the first series of observations was simply to ascertain the times of

high and low water, for the purpose of ascertaining the durations of the rise and fall of the tide. With this view, the depression of the water below the wharf was observed at the four quarters-of-hour nearest to the time of high water, and at the seven quarters-of-hour nearest to the time of low water (a greater number of observations being made near low water, because less is known, from other observations, of the time of low water). And I proposed, by combining the observations of each group, to find the times of high water and of low water much more accurately than by the rude observation of the highest or the lowest water. But in discussing the low-water observations, I found an unexpected difficulty. The rise of the water at a given interval after low water (in half an hour, for instance) is *considerably* more rapid than its descent at the same interval before low water. There is in fact the rudiment of a veritable *bore*. It is impossible here to use any observations for determining the time of low water except those which are very near to the low water.

My curiosity was now excited to learn with a little more precision the laws of the rise and fall of the water generally. For this purpose, Captain SHIRREFF undertook, at my request, to arrange for the observation of the depression of the water at every quarter-of-an-hour, night and day, during half a lunation. This was done, so far as I can judge, with the most perfect regularity. The observations commenced at February 16, 12^h 15^m, astronomical time, and finished at March 4, 12^h 0^m. The whole number of observations is 1536.

In the computation of these observations it is to be considered that the times of high and low water are subject to perpetual irregularities, as well from the change of conformation of the sun and moon, as from the effects of the wind: and also that the heights are more conspicuously variable from the same cause. But there is this difference between them, as regards the mode of treating the observations on the present occasion. The times of high water at London are predicted with considerable accuracy in the Nautical Almanac: and though the time of high water at Deptford, even when undisturbed, is not the same as at London, yet its difference may be supposed to be nearly constant, and therefore the time of high water at London will be a proper zero of phase to which to refer the Deptford tides. But there is no prediction whatever of the depressions of the Deptford high and low waters; and therefore it appears impracticable to take any zero except the observed least and greatest depressions. These considerations suggested the following methods of reducing the observations:—

The time, between one predicted high water for London and the next, was supposed to correspond to 360° of *phase*; and the interval of each time of Deptford observation from the preceding London predicted time of high water was converted into *phase* by that proportion.

The space, between the least depression and greatest depression in one semi-tide (rise or fall), was supposed to correspond to 2, or the double radius; and the depression of the water at each Deptford observation below the least depression of that semi-tide was converted into parts of 1 or radius by that proportion.

I may remark that the results from the various tides would have agreed more exactly if an observed time of Deptford high water had been used (in the conversion of time into phase) instead of predicted time of London high water: but the process would have been more troublesome, and the advantage very small.

As there was evidently a variation in the law depending on the range of the tide, the observations were next divided into two nearly equal groups; one (of fifteen complete tides) comprising those in which the range was small; the other (of sixteen tides) comprising those in which the range was large. The former is called division A, and the latter division B. These two divisions were treated separately; although the methods of treating them are in every respect the same.

The next step was (in each division) to pick out all the phases included between 0° and 10°, and their corresponding converted depressions; and to take the mean of each of these series of numbers: then to pick out all the phases included between 10° and 20°, and their corresponding converted depressions; and to take the mean of each of these series of numbers: and so on. In this manner there were obtained, in each division, two columns of numbers (every one of which was the mean of about twenty-two numbers); one of them being a series of phases very near to 5°, 15°, &c., and the other being the corresponding converted depression. As there was no difficulty in inferring from these numbers, with considerable accuracy, the change of converted depression corresponding to a very small change of phase, it was easy to apply the correction required to adapt the converted depressions to the exact values of phase 5°, 15°, 25°, &c. In this manner the two following Tables were formed.

Division A.

Mean depression of high water 5 ft. 11 in.
Mean range of tide 15 ft. 3 in.

Phase.	Converted depression.	Phase.	Converted depression.
5°	0·068	185°	1·980
15	0·167	195	1·955
25	0·318	205	1·845
35	0·476	215	1·731
45	0·626	225	1·581
55	0·783	235	1·413
65	0·921	245	1·266
75	1·062	255	1·075
85	1·183	265	0·921
95	1·299	275	0·760
105	1·438	285	0·612
115	1·525	295	0·468
125	1·645	305	0·347
135	1·725	315	0·236
145	1·810	325	0·135
155	1·885	335	0·057
165	1·934	345	0·021
175	1·965	355	0·016

Division B.

Mean depression of high water 3 ft. 6 in.
Mean range of tide 19 ft. 2 in.

Phase.	Converted depression.	Phase.	Converted depression.
5°	0·030	185°	1·912
15	0·118	195	1·960
25	0·249	205	1·981
35	0·406	215	1·923
45	0·563	225	1·753
55	0·697	235	1·568
65	0·830	245	1·366
75	0·942	255	1·156
85	1·057	265	0·988
95	1·171	275	0·830
105	1·272	285	0·683
115	1·371	295	0·557
125	1·469	305	0·454
135	1·558	315	0·347
145	1·645	325	0·232
155	1·725	335	0·116
165	1·794	345	0·042
175	1·851	355	0·008

If we express the numbers in these two columns by series of sines and cosines of multiple arcs, we find the following expressions:—

Division A (neap tides).

$$\begin{aligned}\text{Converted depression} &= 1{\cdot}035\\ &\quad + 0{\cdot}198 \text{ sine phase} - 0{\cdot}918 \cos \text{phase}\\ &\quad + 0{\cdot}064 \text{ sine } 2 \text{ phase} - 0{\cdot}016 \cos 2 \text{ phase}\\ &\quad - 0{\cdot}010 \text{ sine } 3 \text{ phase} - 0{\cdot}047 \cos 3 \text{ phase}\\ &\quad + 0{\cdot}008 \text{ sine } 4 \text{ phase} - 0{\cdot}009 \cos 4 \text{ phase}\\ &= 1{\cdot}035 - 0{\cdot}939 \cos (\text{phase} + 12^\circ\, 10') + 0{\cdot}066 \text{ sine } (2 \text{ phase} - 14^\circ\, 2')\\ &\quad - 0{\cdot}048 \cos (3 \text{ phase} - 12^\circ\, 1') + 0{\cdot}012 \text{ sine } (4 \text{ phase} - 48^\circ\, 22').\end{aligned}$$

If we make *phase* $+ 12^\circ\, 10' = p + 90^\circ$, and if we remark that, to obtain the actual depression in feet and inches below the top of the wharf-wall, we must multiply the converted depression by half the range, and must add to the product the depression of high water, we find for the actual depression,

$$5 \text{ ft. } 11 \text{ in.} + \frac{15 \text{ ft. } 3 \text{ in.}}{2} \times \left\{ \begin{array}{l} 1{\cdot}035 + 0{\cdot}939 \,.\, \text{sine } (p) - 0{\cdot}066 \,.\, \text{sine } (2p - 38^\circ\, 22') \\ \quad - 0{\cdot}048 \text{ sine } (3p - 48^\circ\, 40') + 0{\cdot}012 \text{ sine } (4p - 97^\circ\, 2') \end{array} \right\},$$

or

$$13 \text{ ft. } 10 \text{ in.} + 7 \text{ ft. } 7{\cdot}5 \text{ in.} \times \left\{ \begin{array}{l} 0{\cdot}939 \text{ sine } (p) - 0{\cdot}066 \text{ sine } (2p - 38^\circ\, 22') \\ \quad - 0{\cdot}048 \text{ sine } (3p - 48^\circ\, 40') + 0{\cdot}012 \text{ sine } (4p - 97^\circ\, 2') \end{array} \right\},$$

where p represents an angle increasing uniformly with the time and going through a change of 360° in one complete tide.

Division B (spring tides).

$$\begin{aligned}\text{Converted depression} &= 1{\cdot}017\\ &\quad + 0{\cdot}057 \text{ sine phase} - 0{\cdot}900 \text{ cosine phase}\\ &\quad + 0{\cdot}104 \text{ sine } 2 \text{ phase} - 0{\cdot}022 \text{ cosine } 2 \text{ phase}\\ &\quad - 0{\cdot}054 \text{ sine } 3 \text{ phase} - 0{\cdot}043 \text{ cosine } 3 \text{ phase}\\ &\quad + 0{\cdot}016 \text{ sine } 4 \text{ phase} - 0{\cdot}029 \text{ cosine } 4 \text{ phase}\\ &= 1{\cdot}017 - 0{\cdot}902 \text{ cosine } (\text{phase} + 3^\circ\, 37') + 0{\cdot}106 \text{ sine } (2 \text{ phase} - 11^\circ\, 57')\\ &\quad - 0{\cdot}069 \,.\, \text{cosine } (3 \text{ phase} - 51^\circ\, 28') + 0{\cdot}033 \text{ sine } (4 \text{ phase} - 61^\circ\, 7').\end{aligned}$$

If we make *phase* $+ 3^\circ\, 37' = p + 90^\circ$, we find as before for the actual depression of the water below the top of the wharf-wall,

$$3 \text{ ft. } 6 \text{ in.} + \frac{19 \text{ ft. } 2 \text{ in.}}{2} \times \left\{ \begin{array}{l} 1{\cdot}017 + 0{\cdot}902 \,.\, \text{sine } (p) - 0{\cdot}106 \text{ sine } (2p - 19^\circ\, 11') \\ \quad - 0{\cdot}069 \text{ sine } (3p - 62^\circ\, 19') + 0{\cdot}033 \text{ sine } (4p - 75^\circ\, 35') \end{array} \right\},$$

or

$$13 \text{ ft. } 3 \text{ in.} + 9 \text{ ft. } 7 \text{ in.} \times \left\{ \begin{array}{l} 0{\cdot}902 \,.\, \text{sine } (p) - 0{\cdot}106 \text{ sine } (2p - 19^\circ\, 11') \\ \quad - 0{\cdot}069 \text{ sine } (3p - 62^\circ\, 19') + 0{\cdot}033 \text{ sine } (4p - 75^\circ 35') \end{array} \right\},$$

where (as before) p represents an angle increasing uniformly with the time, and going through a change of 360° in one complete tide.

On these expressions we may make the following remarks:—

1st. The mean height of water (understanding by the mean height that part of the expression for the height which is independent of sines and cosines of periodical terms) is, at Deptford, not the same for spring tides and for neap tides. The mean height in the average of the high tides is 13 ft. 3 in. below the top of the wharf-wall, and in the average of the low tides is 13 ft. 10 in. below the same point; or the mean height in high tides is greater than the mean height in low tides by seven inches. The corresponding difference in the whole range of the tide is about four feet.

2nd. The curves representing the law of rise and fall of the water are different for high tides and for low tides, and both are sensibly different from the line of sines. This is evident from the algebraical expression, which contains other terms than those depending on the sine and cosine of the simple phase: but it will be more evident to the eye on the comparison of the curves as graphically traced. In Plate I. the strong line represents the law of depression of the surface of the water through every instant of a tide, the horizontal abscissa representing the time or rather the phase, and the vertical ordinate measured downwards representing the depression (as taken from the Table, page 4) for division A (neap tides): the faint line is a line of sines, whose highest point coincides with the highest point of the tide-curve (supposed to have the converted depression 0·013 for phase 350°), and whose lowest point is depressed as far as the lowest point of the tide-curve (supposed to have the converted depression 1·982). In Plate II. the curves are similarly traced for division B; the highest point of the tide-curve is supposed to have the converted depression 0·008 for phase 355°, and the lowest point is supposed to have the converted depression 1·982.

3rd. If we investigate the motion of a very long wave (as a tide-wave) in a rectangular canal whose section is everywhere the same, on the supposition that the extent of vertical oscillation bears a sensible proportion to the mean depth of the water: putting k for the mean depth, $v^2 = g\,k$, and X for the horizontal displacement of any particle (x being its original horizontal ordinate), we find the following partial differential equation:—

$$\frac{d^2 X}{d t^2} = \frac{v^2 \cdot \dfrac{d^2 X}{d x^2}}{\left(1 + \dfrac{d X}{d x}\right)^3}.$$

This equation cannot (it appears) be solved in finite terms, but it may be solved approximately by successive substitution. Putting it in the shape

$$\frac{d^2 X}{d t^2} - v^2 \frac{d^2 X}{d x^2} = v^2 \frac{d^2 X}{d x^2} \times \left\{ -3 \frac{d X}{d x} + 6 \left(\frac{d X}{d x}\right)^2 - \&c. \right\}$$

and first neglecting the second side of the equation entirely, and solving without it; then substituting the solution (adopting that form of function which is adapted to the sea-tide at the mouth of the canal) in the first term on the second side, and solving again; then substituting the solution in the two first terms on the second side and solving again, &c., we find as many terms as we please for X. Then the vertical

elevation V of the surface, corresponding to the particle whose original horizontal ordinate was x, is found by the equation $\mathrm{V} = \frac{k}{1 + \frac{d\mathrm{X}}{dx}}$. In order to find the elevation not of a given *particle* but at a given *place*, we must approximately express x, the original ordinate of the particle, in terms of x', the ordinate of the place. After all these operations, putting m for the constant which makes $m v t$ to change through 360° in one complete tide, and putting $k b$ for the coefficient of the first variable term, we find for the elevation of the water,

$$\mathrm{V} = k \left\{ 1 - b \sin (m v t - m x') + \frac{33}{32} b^3 . m x' . \cos (m v t - m x') \right.$$
$$+ \frac{9}{32} b^3 . m^2 x'^2 . \sin (m v t - m x') + \frac{3}{4} b^2 . m x' . \sin (2 m v t - 2 m x')$$
$$\left. - \frac{21}{32} b^3 . m x' . \cos (3 m v t - 3 m x') - \frac{27}{32} b^3 . m^2 x'^2 . \sin (3 m v t - 3 m x') \right\},$$

where the approximation is carried to the third power of b. This expression supposes the canal unlimited at the end furthest from the sea. If the canal is stopped by a barrier, the expression changes its form. Putting a for the distance of the barrier from the sea, the elevation at the point x' is represented by

$$\mathrm{V} = k \left\{ 1 - \frac{c . \cos (m a - m x')}{\cos m a} \sin m v t + \frac{c^2}{8 \cos^2 m a} \big(\cos (2 m a - 2 m x') - \cos 2 m a\big) \right.$$
$$\left. + \frac{3 . c^2 . m x' . \sin (2 m a - 2 m x')}{8 \cos^2 m a} \cos 2 m v t \right\},$$

or, putting $k b$ for the coefficient of the first variable term, and omitting that term which does not vary with the time,

$$\mathrm{V} = k \left\{ 1 - b \sin m v t + \frac{3}{4} b^2 . m x' . \tan (m a - m x') . \cos 2 m v t \right\},$$

where the approximation is carried to the second power of b. Neither of the supposed circumstances corresponds exactly to the case of a tidal river; but it may with some reason be supposed to be represented by something intermediate to them; the bridges and other impediments in the upper part producing in some degree the same effect as a barrier. The slope of the sides of the channel alters the magnitude of the coefficients, but does not appear to alter the general form of the expressions: the investigation, however, though not difficult, is so troublesome that I have not completed it. Thus from theory we should expect the variable part of the converted depression to be expressed by a formula intermediate to the two following, the multiplier $k b$ being omitted:

$$+ \sin (m v t - m x') - \frac{3}{4} b . m x' . \sin (2 m v t \quad 2 m x'),$$

$$+ \sin m v t - \frac{3}{4} b . m x' . \tan (m a - m x') . \cos 2 m v t.$$

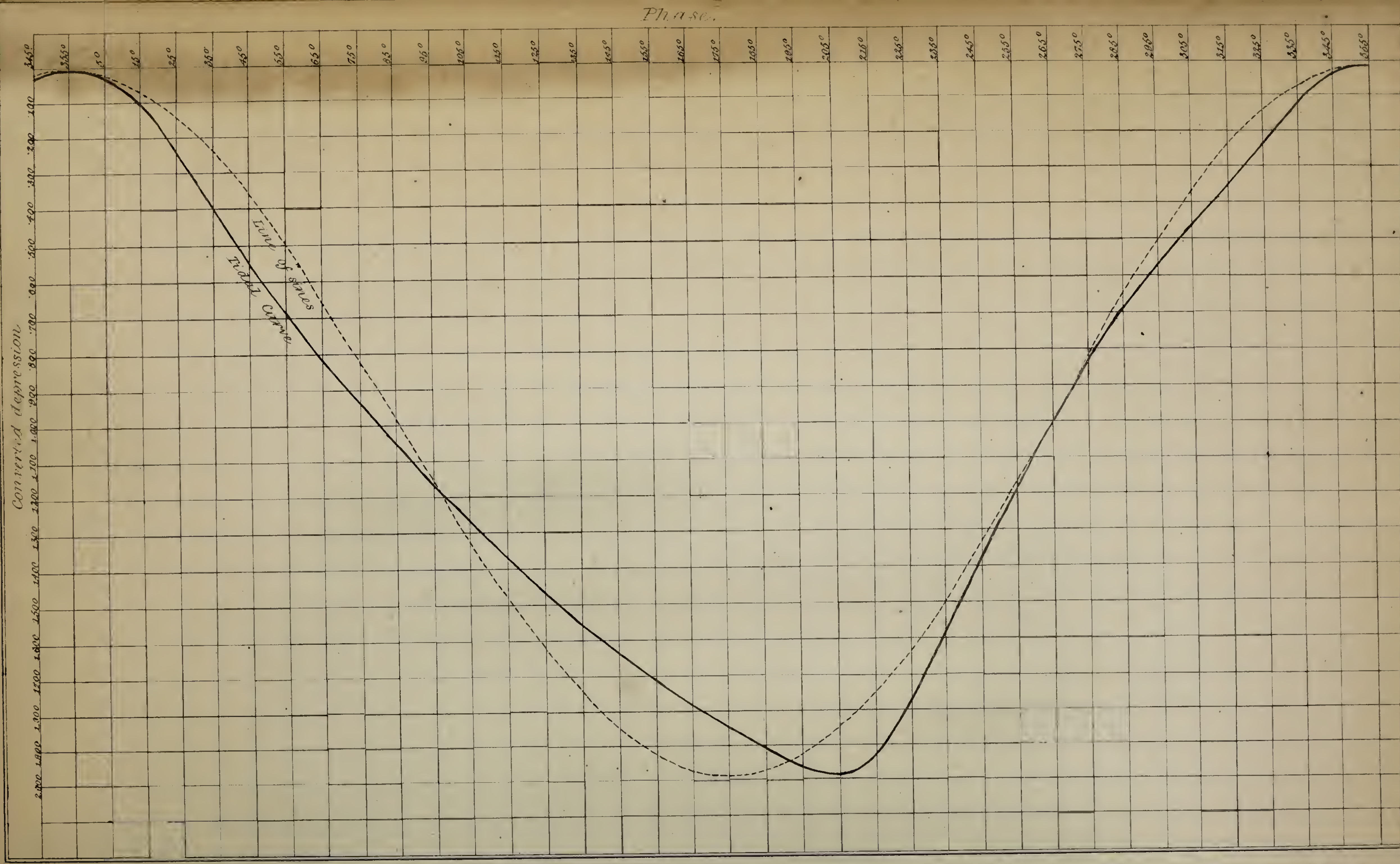


Fig. 2. Curve representing the law of fall and rise of the tide at Deptford, when the whole range of tide is 19 feet 2 Inches.

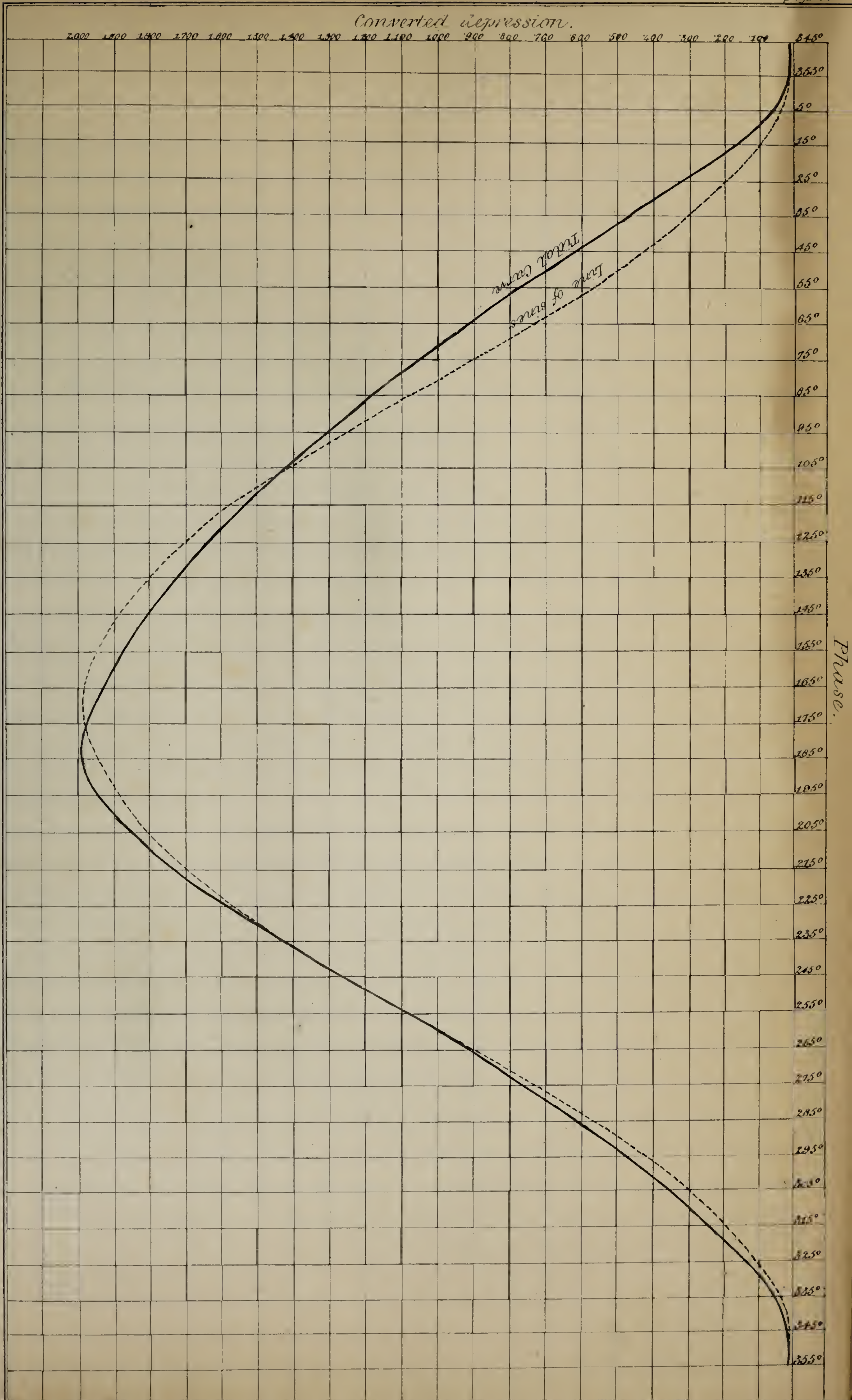


Fig. 1. Curve representing the law of fall and rise of the tide at Deptford, when the whole range of tide is 15 feet 3 inches.

To see clearly the import of this, suppose that our intermediate formula is to be half the sum of these two expressions. Its form then becomes

$$+\cos\frac{mx'}{2}\cdot\sin\left(mvt-\frac{mx'}{2}\right)$$

$$-\frac{3}{8}b.mx'\left\{\cos 2mx'.\sin 2mvt-\left(\sin 2mx'-\tan(ma-mx')\right)\cos 2mvt\right\}.$$

Let

$$\frac{\sin 2mx'-\tan(ma-mx')}{\cos 2mx'}=\tan(2mx'-\mathrm{D}),$$

then the expression may be put in the form

$$+\mathrm{B}\sin\left(mvt-\frac{mx'}{2}\right)-\mathrm{C}\sin(2mvt-2mx'+\mathrm{D}),$$

or, if $mvt-\frac{mx'}{2}=p$, the theoretical converted depression is

$$+\mathrm{B}\sin p-\mathrm{C}\sin(2p-mx'+\mathrm{D}).$$

When $ma-mx'$ is not large (as it certainly cannot be at Deptford), mx' is greater than D, and the theoretical converted depression, putting A for $mx'-\mathrm{D}$, is

$$+\mathrm{B}\,.\sin p-\mathrm{C}\,.\sin(2p-\mathrm{A}).$$

This is precisely the same form as that given by the discussion of the observations.

4th. According to the theory, the coefficient of the second variable term in the expression for the converted depression ought to be proportional to the range of the tide (for it contains b as a factor). In the discussion of the observations it appears that this coefficient increases more rapidly than b. This seems to render it probable that terms of sensible magnitude would be introduced by pushing the approximation to the fourth and higher orders.

5th. Suppose then that the variable part of the converted depression is represented by $\sin\theta-c\sin(2\theta-\mathrm{A})$, where θ, as appears from the theory, is $mvt-mx'$, or is the value of the phase depending simply on the depth of the canal and the distance of the point of observation from the sea, or is that value of phase which would correspond to a shallow wave passing along the canal. The values of θ for high and low water will be those which satisfy the equation $\cos\theta-2c\,.\cos(2\theta-\mathrm{A})=0$. Solving this equation for high water, by successive substitution, we have as a first approximation $\cos\theta=0$, or $\theta=270°$; $\cos(2\theta-\mathrm{A})=\cos(540°-\mathrm{A})=-\cos\mathrm{A}$; using this substitution in the second term, the equation becomes $\cos\theta+2c\cos\mathrm{A}=0$; or if $\theta=270°+x$, $\sin x+2c\cos\mathrm{A}=0$, or $x=-2c\,.\cos\mathrm{A}$ nearly, and therefore the value of $mvt-mx'$ for high water is $270°-2c\cos\mathrm{A}$ nearly. In the same way it is found that the value of $mvt-mx'$ for low water is $90°+2c\cos\mathrm{A}$ nearly. So far, therefore, as depends on this term, the high water is accelerated and the low water is retarded by nearly equal terms: and this acceleration and retardation are proportional to c, or to b, or to the whole range of the tide: and are therefore greater for spring tides than for neap tides.

6th. This remark enables us to explain a circumstance which appeared somewhat perplexing. It has been found by Sir J. W. LUBBOCK and Mr. WHEWELL that the age of the tide is different, as inferred from the *height* of the high water, or from the *time* of high water: the age of the tide always appearing greater as inferred from the *heights**. Now to explain this, we have to consider that, at syzygies of the sun and moon, the time of high water in the sea is on every successive day earlier with respect to the moon's transit; but the syzygial or spring tide in the river, and the tides near it, are (as we have just found) accelerated with respect to the sea-tide more than mean tides are: and therefore the river tide which happens at the mean interval from the moon's transit is not the syzygial tide, but a tide preceding it. But there is no corresponding effect produced on the height of the tide. Thus the age of the tide inferred from the height is the true age (at least as far as it can be ascertained from the phenomena of the ocean-tides); the age as inferred from the time of high water is certainly too small, and the quantity by which it is too small depends on the length and depth of the river, or of the shallows along which the tide has to pass.

I have only to add the following deductions from the observations.

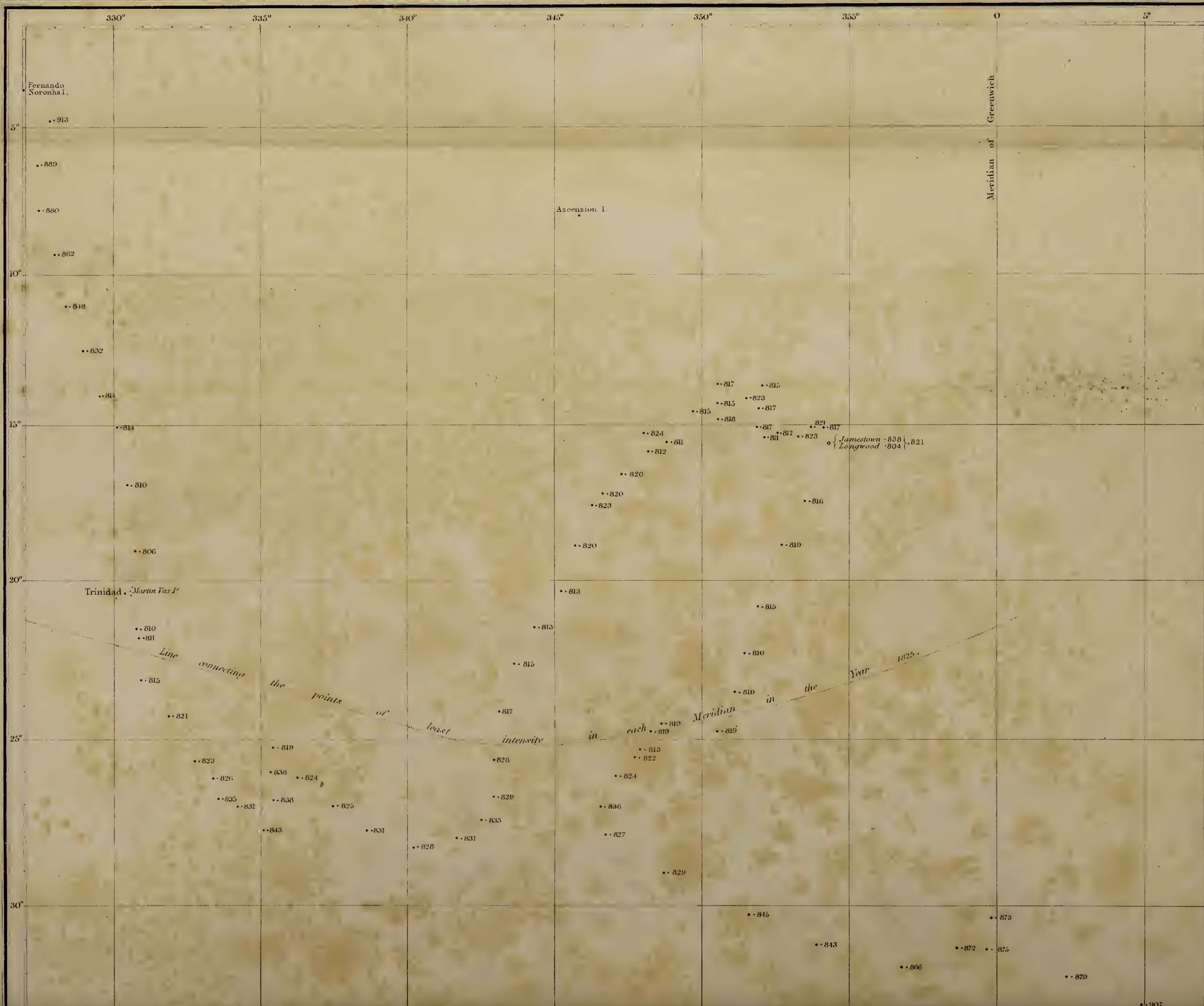
In division A (low tides) the high water occurred at the phase 350° nearly, that is, about 20^m before the predicted time of high water at London Bridge: the low water occurred at the phase 185° nearly: the interval between high water and low water was about 195° of phase, and that between low water and high water about 165° of phase; or the descent occupied a longer time than the ascent by 30° of phase, or a little more than an hour of time.

In division B (high tides) the high water occurred at the phase 355° nearly, or about 10^m before the predicted time of high water at London Bridge: the low water occurred at the phase 205° nearly; the descent therefore occupied 210° of phase, and the ascent 150°; or the time of descent exceeded that of ascent by 60° of phase, or $2^h\ 4^m$ of time.

The times of the turn of the tide-current, as shown by the swinging of the ships at anchor in the river, were regularly observed. The means of the corresponding phases in division A are 10°·4 and 204°·4, or nearly 20° of phase or 40^m of time after high and low water respectively: those in division B are 14°·0 and 223°·5, or nearly 18°·5 of phase or 37^m of time after high and low water respectively.

* LUBBOCK, Philosophical Transactions, 1837. WHEWELL, Philosophical Transactions, 1838.

Royal Observatory, Greenwich,
June 25, 1841.


South Latitude
Meridian of Greenwich
Meridian 0 of Greenwich
Fernando Noronha I.
Ascension I.
Jamestown ·838
Longwood ·804
·821
Trinidad
Martin Vas Is
Line connecting the points of least intensity in each Meridian in the Year 1825

II. *Contributions to Terrestrial Magnetism.—No. III.*

By Lieut.-Colonel EDWARD SABINE, *R.A., F.R.S.*

Received December 16, 1841,—Read January 20, 1842.

IN the present number of these Contributions, I propose to give an account of the observations on the magnetic intensity made at sea by the officers of Her Majesty's ships Erebus and Terror, on their passage from England to Kerguelen Island, the unreduced observations, transmitted to the Admiralty by the Commanders, Captains Ross and CROZIER, having been placed in my hands for that purpose.

They will be divided for convenience into two sections, viz.

§ 5. *Observations between England and the Cape of Good Hope.* § 6. *Observations between the Cape of Good Hope and Kerguelen Island.*

§ 5. *Observations between England and the Cape of Good Hope.*

The observations in the Erebus were made by the statical method devised by Mr. Fox, with one of his instruments of $7\frac{1}{2}$ inches diameter. The intensities were measured by the angles of deflection produced, in different localities, by a constant weight applied to a grooved wheel on the axle of the needle; and the ratio of the intensities is inversely as the sines of the angles of deflection, subject to a correction for differences of temperature of the needle, computed by the formula $\cdot 00016\ \mathrm{I}'\ (t'-t)$, in which t is the standard and t' the observed temperature in degrees of FAHRENHEIT, ·00016 a coefficient determined experimentally by Mr. Fox, and I′ the observed intensity. At sea, where the manipulation of the weights causes an exposure of the needle, which, in bad weather particularly, is liable to occasion injury, the plan recommended by Mr. Fox, of using deflecting magnets instead of weights, was frequently resorted to. In this case the ratio of the intensity in different localities is inversely as the sines of the angles of deflection, and directly as the weights equivalent to the deflecting force of the deflector on the needle at the respective angles; or

$$\mathrm{I}' = \mathrm{I} \cdot \frac{w'}{w} \cdot \frac{\sin v}{\sin v'},$$

where I, v, and w are the intensity, angle of deflection, and equivalent weight at a base station; and I′, v', and w' corresponding values at another station. A table is usually formed for each instrument experimentally, under Mr. Fox's own direction, of the equivalent, or as they are termed by him, the *coercing* weights, for each deflector on each of the needles at the different angles which are likely to occur in the course of the observations. This is done by placing the deflector successively at

angles from the dip*, each differing one degree from the preceding; the needle is thereby deflected to a smaller angle on the side of the dip opposite to the deflector, and is brought back to the dip by a weight applied to the grooved wheel on the axle; this weight is called the coercing weight corresponding to the angle from the dip at which the deflector was placed. For greater accuracy, the table is formed from results obtained by placing the deflector successively on either side of the needle. Owing to accidental circumstances, no table of this description was prepared for this instrument before the Expedition sailed; the pressure of other duties prevented its being done at St. Helena, the Cape of Good Hope, or at Kerguelen Island; and at Van Diemen Island the end of the axle of the needle being accidentally broken, the needle was returned to England to be repaired, and was thus separated from the instrument and from the deflectors. Under these circumstances we have no other resource for reducing the observations made with the deflectors, than to form a table from the observations of the weights and deflectors (when both methods have been employed at the same station), which shall answer the same purpose as a table of coercing weights. Fortunately the number of such stations is considerable.

We may form this table in the following manner. For the primary or base station, let V be the angle of deflection with a constant weight W, and v the angle of deflection produced by the deflector placed at the dip, then is

$$w = \mathrm{W} \sin v \operatorname{cosec} \mathrm{V},$$

w being the weight equivalent to the deflecting force of the deflector at the angle v. If several constant weights were used at the primary station, the value of w may be obtained from each separately, and an arithmetical mean taken. Then at another station, at which the angles of deflection have been observed both with the deflector and with constant weights, the equivalent weight w' to the angle v' produced by the deflector may be obtained from

$$w' = \frac{\mathrm{I}' w \sin v'}{\mathrm{I} \sin v},$$

I being the intensity at the primary station, and I′ the intensity derived by the method of constant weights at the other station. The values of w', thus computed for all the stations where the weights and deflectors were both used, being projected in a graphical representation with the corresponding values of v', the former as ordinates, the latter as abscissæ, a line drawn by the eye through the terminations of the ordinates will give the values of w' for each degree of v' produced by the deflector.

In the intensity instrument of the Erebus two deflectors were used, sometimes separately and sometimes combined: they were designated N. and S, according to the pole of the needle to which they were respectively applied. They were contained in brass tubes, N. with its north pole, and S. with its south pole towards the end of the tube which screwed into the limb of the instrument; consequently "Deflector N." in

* This analysis may be made when the needle is in other positions, but Mr. Fox now prefers the *vertical* one, or when the needle stands at 90°, the circle being perpendicular to the plane of the magnetic meridian.

the Table signifies that the deflector having its north pole towards the screw was placed opposite that division of the circle which the north end of the needle had previously indicated as the dip; and the angle of deflection v' is a mean of the deflections of the needle, first on the one side and then on the other side of the deflector.

In the case of this deflector we have the angle v observed in London 22° 57′; and the value of w, derived from the angles with the four constant weights of 1, 2, 3, and 4 grains, = 2·114 grs. Regarding London as the primary station, and the intensity = 1, the values of w' at the several stations where both weights and deflectors were used are found by

$$w' = 5{\cdot}422\ \mathrm{I}' \sin v'.$$

The table of observations furnishes seventy-four occasions between England and the Cape of Good Hope, in which this deflector was used in comparison with the constant weights: we have consequently so many values of w' from which to form a table for each degree of deflection. The angles v' produced by this deflector increased from 22° 57′ in London to above 34° where the intensity was weakest, and again decreased to 29° 53′ at the Cape; consequently the ordinates corresponding to the smaller angles are derived partly from the earlier and partly from the later observations of the series. The line drawn freely through the points forming the terminations of the ordinates shows by its continuity that the force of the deflector remained unchanged during the whole of the series; it exhibits no discordances with any of the values of w', but such as may well be attributed to the unavoidable discrepancies of single observations. By means of this graphical representation the subjoined Table has been formed of the values of w' for each degree of v', permitting the intensities I′ to be computed, relative to the force unity in London, by the formula

$$\mathrm{I}' = {\cdot}1845\, w' \operatorname{cosec} v'.$$

Values of w', Deflector N.

°	grs.	°	grs.
23	= 2·113	30	= 1·929
24	= 2·085	31	= 1·904
25	= 2·058	32	= 1·880
26	= 2·031	33	= 1·857
27	= 2·005	34	= 1·834
28	= 1·979	35	= 1·810
29	= 1·954		

In the case of deflector S, the table of observations furnishes 109 occasions between London and the Cape of Good Hope in which the angle v' was observed in comparison with the angles produced by the constant weights; consequently we have 109 values of w' to be combined in a graphical representation. The line freely drawn through the terminations of the ordinates is continuous from August 1839 to the noon-observation of February 12, 1840, when the continuity becomes interrupted, and a second line, corresponding to a diminished force in the deflector, commences, and continues unbroken to the Cape of Good Hope. The loss of force in the de-

flector, which occurred between the forenoon and afternoon observations of the 12th of February, was equivalent to nearly a degree in the angle v', and is obvious on a simple inspection of the table of observations. In this case, therefore, we require to form two tables of the values of w'; the one, Table A, corresponding to the force of the deflector between August 1839 and February 12th, 1840, and the other, Table B, to the weaker force between February 12th and the Cape of Good Hope.

Values of w', Deflector S.

(A.) August 1839 to February 12, 1840.		(B.) February 12 to March 25, 1840.
° grs.	° grs.	° grs.
30 = 2·754	37 = 2·410	35 = 2·291
31 = 2·704	38 = 2·359	36 = 2·260
32 = 2·655	39 = 2·310	37 = 2·235
33 = 2·606	40 = 2·260	38 = 2·210
34 = 2·556	41 = 2·210	39 = 2·186
35 = 2·508	42 = 2·160	40 = 2·161
36 = 2·459	43 = 2·110	41 = 2·135
		42 = 2·110

For the first series we have London as the primary station, where $I = 1, v = 30° 19'$, and $w = 2·737$; whence

$$I' = ·1845\, w' \operatorname{cosec} v'.$$

the values of w' being taken from Table A. And for the second series we have the Cape as the primary station, where $v = 35° 40'$, $w = 2·270$, and I, derived from the experiments with the constant weights $= 0·715$ (London $= 1$); consequently at other stations

$$I' = ·1837\, w' \operatorname{cosec} v'.$$

the values of w' being taken from Table B.

The loss of force sustained by deflector S. causes a similar interruption in the continuity of the line connecting the terminations of the ordinates derived from the observations in which the deflectors N. and S. were used conjointly; we have therefore in this case also two tables of the values of w', one for the first, and the other for the second series.

Values of w', Deflectors N. and S.

(A.) August 1839 to February 12, 1840.		(B.) February 12 to March 25, 1840.
° grs.	° grs.	° grs.
44 = 3·784	53 = 3·118	51 = 3·037
45 = 3·674	54 = 3·056	52 = 2·989
46 = 3·584	55 = 2·995	53 = 2·943
47 = 3·505	56 = 2·936	54 = 2·896
48 = 3·430	57 = 2·880	55 = 2·853
49 = 3·366	58 = 2·828	56 = 2·813
50 = 3·304	59 = 2·780	57 = 2·775
51 = 3·242	60 = 2·738	58 = 2·740
52 = 3·180		

For the first series we have London as the primary station, where $I = 1$, $v = 44° 06'$, and $w = 3{\cdot}773$; whence at other stations

$$I' = {\cdot}1845\, w' \operatorname{cosec} v',$$

w' being taken from Table A; and for the second series the Cape as the primary station, where $I = 0{\cdot}715$, $v = 51° 10'$, and $w = 3{\cdot}032$; whence at other stations

$$I' = {\cdot}1837\, w' \operatorname{cosec} v',$$

w' being taken from Table B.

Table I. contains the observations made with the weights and deflectors on shore and on board the Erebus, between London and the Cape of Good Hope. Of 647 observations comprised in this Table, I have only found it necessary to consider a single one as doubtful, namely, the second observation with the constant weight of one grain at the Cape of Good Hope; its result differs so much from that of the observation on the preceding day with the same weight, and with those of the preceding and of the same day with the weight of $1\frac{1}{2}$ grain, that I have thought it safer to omit it in taking the mean of the results at that station; but the observation itself, and its result, are both given in the Table.

Table I.

Observations of the Magnetic Intensity on Shore, and on Board Her Majesty's Ship Erebus, with Needle F, by Captain James Clark Ross.

London to the Cape of Good Hope.

1839.	Position. Lat.	Position. Long. E.	Time of day.	Method employed.	Deflection observed.	Thermometer.	Ship's head.	Intensity. London = 1·000		Intensity. = 1·372
			h m		° ′	°				
Aug. 28.	Westbourn Green near London.		5 P.M.	Deflector S.	30 19	70				
				Deflector N.	22 57					
				Deflectors S. & N.	44 6		Observed on shore.			
				weight 1 grain.	10 34			1·000		1·372
				weight 2 grains.	21 47					
				weight 3 grains.	33 24					
				weight 4 grains.	47 52					
Oct. 1.	50° 42′	0° 35′	1 P.M.	S.	30 38	60		·985		
			11 A.M.	weight 2 grains.	21 54		W. by N.	·993	·990	1·358
			Noon.	weight 4 grains.	48 17			·992		
3.	50 17	357 26	10 30 A.M.	weight 2 grains.	21 41	60	W. by N.	1·003	1·001	1·373
				weight 4 grains.	47 45			1·000		
8.	47 47	350 42	10 A.M.	S.	30 43	56	S.W. by W.	·981	1·007	1·382
				weight 2 grains.	21 1			1·033		
13.	41 6	348 10	9 A.M.	S.	30 43	61	S.W. by W.	·982		
				S. and N.	45 1			·959	·966	1·326
				weight 2 grains.	22 43			·959		
14.	39 30	347 51	9 30 A.M.	S.	30 22	65	S.W. by W.	·993		
			10 15 A.M.	S. and N.	44 35			·978	·977	1·346
			11 0 A.M.	weight 2 grains.	22 45			·959		
21.	Funchal Roads.		10 0 A.M.	S.	31 14	73	W. by S.	·958		
				S. and N.	45 17			·948		
			11 0 A.M.	weight 2 grains.	23 7	73		·946	·949	1·302
				weight 4 grains.	51 45			·945		
23.	Consul's House, Funchal.		7 A.M.	S.	31 18	70		·955		
			10 A.M.	S. and N.	45 17	71	Observed on shore.	·948		
			Noon.	weight 2 grains.	23 12	70		·942	·946	1·297
	32 38	343 04	0 30 P.M.	weight 3 grains.	35 45			·942		
24.?			10 30 A.M.	weight 4 grains.	51 55			·943		
26.	Funchal Roads.		2 0 P.M.	S.	31 10	70	W. by S.	·961		
			3 10 P.M.	weight 1 grain.	11 23	74		·930		
			3 50 P.M.	weight 2 grains.	23 20			·937	·941	1·291
			4 30 P.M.	weight 3 grains.	36 5			·935		
Nov. 1.	30 47	343 10	10 A.M.	S.	31 26	70	S.S.W.	·948		
			to	weight 1 grain.	11 29			·921	·931	1·277
			Noon.	weight 2 grains.	23 39			·925		
4.	Off Santa Cruz, Teneriffe.		10 A.M.	S.	31 53	76	S.S.W.	·929		
			to	weight 1 grain.	11 40			·908	·916	1·256
			Noon.	weight 2 grains.	24 5			·910		
6.	26 1	342 25	10 A.M.	S.	32 34	74	S.W. ½ W.	·900		
			10 20 A.M.	S. and N.	46 42			·894		
			11 15 A.M.	weight 2 grains.	24 37			·892		
			11 50 A.M.	weight 3 grains.	38 48			·879	·905	1·241
			1 30 P.M.	S.	31 34	74	N.W. ½ N.	·943		
			2 0 P.M.	S. and N.	45 58			·920		
7.	24 51	341 18	10 30 A.M.	S.	32 58	77	S.W. ½ W.	·884	·886	1·216
				S. and N.	46 52			·889		
8.	23 40	340 45	0 30 P.M.	S.	33 3	76	S.W. ½ W.	·880		
			4 0 P.M.	S.	33 8	74	S.W. ½ W.	·877		
			1 30 P.M.	S.	32 45	72	E.	·892		
			2 15 P.M.	S.	32 51	73	W.	·888	·883	1·212
			3 0 P.M.	S.	33 4	73	S.	·879		
			3 30 P.M.	weight 1 grain.	11 54		S.W. ½ W.	·890		
			4 0 P.M.	weight 2 grains.	25 12		S.W. ½ W.	·872		

Table I. (Continued.)

1839.	Position. Lat.	Position. Long. E.	Time of day.	Method employed.	Deflection observed.	Thermometer.	Ship's head.	Intensity. London = 1·000		= 1·372.
	° ′	° ′	h m		° ′	°				
Nov. 9.	22 18	340 03	9 A.M.	S.	33 13	74		·874		
			to	N.	25 31			·874		
			11 A.M.	S. and N.	47 24			·871	·874	1·199
			2 P.M.	N.	25 29			·878		
			3 P.M.	weight 1 grain.	11 58	73		·885		
				weight 2 grains.	25 30			·862		
10.	20 54	339 18	1 P.M.	S.	33 32	74		·861		
				weight 1 grain.	12 4			·880	·867	1·190
				weight 2 grains.	25 38			·859		
11.	19 8	338 07	9 A.M.	S.	33 56	76	S.W. ½ W.	·846		
				N.	25 54			·859	·854	1·171
				S. and N.	47 49			·858		
12.	17 10	336 55	10 30 A.M.	S.	34 8	78		·839		
				N.	26 0			·855		
				S. and N.	48 4			·850	·849	1·164
			Noon. to	weight 1 grain.	12 14	78		·866		
			1 P.M.	weight 2 grains.	26 6			·845		
				weight 3 grains.	41 0			·840		
14.	Quail Island.		10 A.M.	S.	34 4	91		·841		
			to Noon.	N.	25 59			·855		
	14 54	336 30		S. and N.	48 15		Observed	·844	·844	1·157
			1 30 P.M.	weight 1 grain.	12 36	93	on shore.	·844		
				weight 2 grains.	26 0			·850		
				weight 3 grains.	41 41			·831		
18.	Porto Praya.		6 to	S.	33 57	74	N.E.	·845		
			7 30 A.M.	S.	34 34	76	E.	·822		
			8 to	S.	33 53	78	N.	·847		
			9 30 A.M.	S.	34 30	79	W.	·825	·840	1·153
			10 to	S.	34 19	80	S.	·833		
			11 30 A.M.	S.	33 13	80	N.W.	·872		
			0 45 P.M.	S.	34 21	80	S.E.	·830		
			3 0 P.M.	S.	33 57	84	S.W.	·845		
21.	12 39	335 35	9 30 to	S.	34 4	79	S.W.	·841		
			11 A.M.	N.	26 8			·849		
				S. and N.	48 51			·827	·831	1·140
				weight 1 grain.	13 2			·815		
				weight 2 grains.	26 50			·824		
22.	11 19	335 07	Noon to	S.	34 46	81	S.W.	·815		
			1 30 P.M.	N.	27 6			·811	·813	1·115
				S. and N.	49 24			·812		
23.	9 48	334 41	11 30 A.M.	S.	35 1	84	S.W.	·806		
			to	N.	27 20			·802		
			1 P.M.	S. and N.	49 50			·800	·793	1·088
			3 to	weight 1 grain.	13 45	83		·773		
			4 P.M.	weight 2 grains.	28 24			·786		
25.	6 52	333 55	10 A.M.	S.	35 59	83	S.S.W.	·772		
				N.	28 38			·756		
				S. and N.	51 6			·767	·763	1·046
				weight 1 grain.	14 3			·757		
				weight 2 grains.	29 14			·761		
26.	5 13	333 35	10 A.M.	S.	36 13	83	S.S.W.	·764		
				N.	29 1			·743	·752	1·032
				S. and N.	51 51			·748		
29.	3 20	332 48	10 A.M.	S.	37 8	82	S.W. by S.	·734		
				N.	29 23			·731	·732	1·004
				S. and N.	52 29			·732		

Table I. (Continued.)

1839.	Position. Lat.	Position. Long. E.	Time of day.	Method employed.	Deflection observed.	Thermo-meter.	Ship's head.	Intensity. London = 1·000.		= 1·372.
	° ′	° ′	h m		° ′	°				
Nov. 30.	2 6	331 25	10 A.M.	S.	37 17	81	S.S.W. ½ W.	·729		
				N.	30 3			·711		
				S. and N.	52 34			·730	·728	·998
				weight 1 grain.	14 30	83		·734		
				weight 2 grains.	30 24			·735		
Dec. 2.	St. Paul's Rocks.		8 A.M.	S.	37 8	90	Observed on shore.	·734		
	0 56	330 40	to	N.	29 34			·725		
			9 30 A.M.	S. and N.	52 44			·726	·727	·997
			3 P.M.	weight 1 grain.	14 39			·727		
				weight 2 grains.	30 50			·726		
3.	0 24	330 19	10 A.M.	S.	37 41	84	S.S.W. ½ W.	·717		
			to	N.	30 11			·706	·712	·977
			11 30 A.M.	S. and N.	53 15			·714		
4.	— 0 28	330 02	11 A.M.	S.	37 46	82	S. by W. ½ W.	·716		
			to	N.	30 29			·697	·700	·960
			Noon.	S. and N.	53 49			·694		
5.	— 1 37	329 17	10 30 A.M.	S.	38 10	83	S.S.W.	·702		
			to	N.	30 29			·697		
			Noon.	S. and N.	54 2			·696	·699	·959
				weight 1 grain.	15 27			·690		
			1 P.M.	weight 2 grains.	32 6			·710		
6.	— 3 18	328 31	10 A.M.	S.	38 47		S.S.W.	·683		
			10 40 A.M.	S. and N.	54 48			·679	·683	·937
			11 30 A.M.	N.	30 51			·686		
7.	— 4 49	327 43	9 30 A.M.	S.	39 7	81	S.S.W.	·674		
				S. and N.	55 1			·674		
				N.	31 24			·671	·672	·921
				weight 1 grain.	16 16	82		·656		
				weight 2 grains.	32 26			·693		
				weight 3 grains.	56 7			·664		
8.	— 6 24	327 24	11 30 A.M.	S.	39 35	82	S.	·659	·654	·897
			Noon.	weight 1 grain.	16 25			·650		
9.	— 7 50	327 28	9 30 A.M.	S.	39 50	80	S.	·652		
			10 10 A.M.	S. and N.	55 50			·657		
			10 45 A.M.	N.	32 47			·635	·648	·888
			11 30 A.M.	weight 1 grain.	16 37	80		·642		
			Noon.	weight 2 grains.	34 42			·653		
10.	— 9 21	327 58		S.	40 13	81	S.S.E.	·642		
				S. and N.	57 2			·633		
				N.	33 7			·626	·635	·870
				weight 1 grain.	16 41	83		·640		
				weight 2 grains.	35 53			·635		
11.	—11 3	328 22		S.	41 0	81	S.S.E.	·622		
				S. and N.	57 18			·628		
				N.	33 29			·617	·624	·856
				weight 1 grain.	17 7	81		·624		
				weight 2 grains	36 8			·631		
12	—12 32	328 57	10 A.M.	S.	41 24	82	S.E. by S.	·611		
			10 55 A.M.	S. and N.	57 23			·626		
			11 45 A.M.	N.	33 40			·613	·611	·840
			1 P.M.	weight 1 grain.	17 56	82	S.S.E. ½ E.	·597		
			2 P.M.	weight 2 grains.	36 56			·619		
13.	—14 00	329 28	0 30 P.M.	weight 1 grain.	18 0	82	S.S.E.	·594		
			1 P.M.	weight 2 grains.	37 57			·605		
			1 15 P.M.	S.	41 51	82		·599	·599	·822
			2 0 P.M.	S.	41 42			·603		
			6 P.M.	weight 1 grain.	18 1	79		·594		

TABLE I. (Continued.)

1839.	Position. Lat.	Position. Long. E.	Time of day.	Method employed.	Deflection observed.	Thermometer.	Ship's head.	Intensity. London = 1·000.		Intensity. = 1·372.
Dec. 14.	−15 4	330 06	10 A.M.	S.	41 58	80	S.S.E.	·596		
				S. and N.	58 17			·610		
				N.	34 13			·600	·599	·822
				weight 1 grain.	18 7	81		·591		
				weight 2 grains.	38 27			·598		
15.	16 52	330 27	9 30 A.M.	S.	42 3	79	S. by E.	·594		
			10 20 A.M.	S. and N.	58 40			·602		
			10 50 A.M.	N.	34 21			·597	·596	·818
			11 10 A.M.	weight 1 grain.	18 10	79		·589		
			Noon.	weight 2 grains.	38 30			·597		
16.	−19 1	330 45	10 A.M	S.	42 12	78	S. ½ E.	·591		
			to	N.	34 23	78		·596		
			Noon.	S. and N.	59 1	78		·598		
			0 15 P.M.	weight 1 grain.	18 7	78		·591	·593	·814
			to	weight 1 grain.	18 14	78		·587		
			2 30 P.M.	weight 2 grains.	38 47	78		·593		
				weight 2 grains.	38 48	78		·593		
17.	Island of Trinidad.		10 A.M.	S.	42 5	80	Observed on shore.	·593		
				N.	34 34	80		·592		
	−20 31	330 38	to	S. and N.	59 1	80		·598	·592	·813
				weight 1 grain.	18 14	80		·587		
			Noon.	weight 2 grains.	38 42	80		·595		
18.	−21 31	330 47	10 A.M.	S.	42 3	78	S.	·594		
			to	N.	34 5			·603		
			Noon.	S. and N.	59 4			·597		
				weight 1 grain.	18 6	79		·591	·596	·818
				weight 1 grain.	18 9			·590		
				weight 2 grains.	38 28			·598		
				weight 2 grains.	38 27			·598		
	−21 47	330 50	5 30 P.M.	S.	42 8	76	S.	·592		
			to	N.	34 13			·600	·597	·819
			7 P.M.	S. and N.	58 55			·598		
19.	−23 8	330 49	9 A.M.	S.	41 52	79	S. ½ W.	·599		
				weight 1 grain.	17 56			·597	·600	·823
				weight 2 grains.	37 37			·609		
	−23 20	331 0	6 P.M.	S.	41 58	76	S.E.	·596		
20.	−24 16	331 45	9 30 A.M	S.	41 16	77	S.E. by S.	·615		
				N.	34 8	77		·602		
			to	S. and N.	59 5	77		·597	·604	·829
			Noon.	weight 1 grain.	17 52	78		·599		
				weight 2 grains.	37 34	78		·610		
	−24 28	331 57	6 P.M.	S.	41 48	76	S.S.E.	·601		
				N.	34 4			·603	·603	·828
				S. and N.	58 33			·606		
21.	−25 38	332 41	10 A.M.	S.	41 56	76	S.E. by E. ½ E.	·599		
			to	N.	34 16	76		·599		
			Noon.	S. and N.	58 46	76		·603		
			0 40 P.M.	weight 1 grain.	17 50	78		·600		
			1 30 P.M.	weight 2 grains.	37 16	78		·614	·603	·828
	−25 42	332 51	5 P.M.	S.	41 50	77	S.E.	·600		
				N.	33 53			·608		
				S. and N.	58 53			·602		
22.	−26 52	333 30	11 A.M.	S.	41 10	77	S.S.E.	·617		
			to	N.	33 43			·611		
			2 P.M.	S. and N.	58 9			·613		
				weight 1 grain.	17 44	78		·603	·612	·839
				weight 1 grain.	17 44		S.S.E.	·603		
				weight 2 grains.	36 56			·618		
				weight 2 grains.	36 56		S.S.E.	·618		

TABLE I. (Continued.)

1839.	Position. Lat.	Position. Long. E.	Time of day.	Method employed.	Deflection observed.	Thermometer.	Ship's head.	Intensity. London = 1·000.		Intensity. = 1·372.
	° ′	° ′	h m		° ′	°				
Dec. 22.	−26 49	333 30	2 to	S.	41 30	77		·608		
			3 P.M.	N.	33 23			·620		
				S. and N.	58 16		N. by E.	·611	·613	·840
				weight 1 grain.	17 42	77		·604		
				weight 2 grains.	36 48			·620		
23.	−26 12	333 20	9 A.M.	N.	33 17	78	N. ½ W.	·622		
			10 A.M.	N.	33 57	78		·606		
			11 A.M.	S.	41 46	78	S.E.	·602		
	−26 12	333 23	Noon.	S. and N.	58 55	78		·599	·607	·833
			0 30 P.M.	weight 1 grain.	17 45	77		·602		
			1 P.M.	weight 2 grains.	37 18			·613		
24.	−27 4	334 10	10 A.M.	S.	41 35	76	E.	·605		
			1 P.M.	S.	41 31	77		·608		
			to	N.	34 0	77		·605		
	−27 4	334 16	3 30 P.M.	S. and N.	58 37			·605	·609	·836
				weight 1 grain.	17 40	76	S.E. by E.	·605		
				weight 2 grains.	36 56			·618		
				weight 2 grains.	36 41			·622		
25.	−27 46	335 04	10 30 A.M.	S.	41 13	76		·615		
			to	N.	33 23	76	S. by E.	·620		
			11 30 A.M.	S. and N.	58 1	76		·615		
			Noon	S.	41 22	76		·611		
			to	N.	33 47			·610	·617	·845
			2 P.M.	S. and N.	58 11		N.N.E. ½ E.	·612		
	−27 41	335 08	2 30 to	weight 1 grain.	17 22	76		·615		
			3 30 P.M.	weight 2 grains.	35 47			·635		
26.	−26 53	335 26	9 to	S.	41 23	76	N.N.E.	·611		
				N.	33 47		N.	·610		
			11 20 A.M.	S. and N.	57 46			·619	·613	·840
			11 30 to	weight 1 grain.	17 40	78	S.S.E.	·605		
			0 30 P.M.	weight 2 grains.	37 0			·618		
27.	−26 6	335 19	10 A.M.	S.	41 41	77		·603		
			to	N.	33 55	77	N. by E.	·607		
			Noon.	S. and N.	58 8	77		·613	·607	·833
	−25 57	335 20	3 30 P.M.	weight 2 grains.	37 46	76	N.E. by N.	·607		
			4 10 P.M.	weight 1 grain.	17 51	76		·599		
28.	−25 21	335 28	10 A.M.	S.	41 55	78		·599		
			to	N.	34 3	78	S.E. by E.	·604		
			Noon.	S. and N.	58 32	78		·607		
			0 45 P.M.	weight 1 grain.	17 51	79	S.E.	·599	·602	·826
			1 30 P.M.	weight 2 grains.	38 12	79		·601		
			6 30 P.M.	weight 1 grain.	17 53	76	S.E. by S.	·598		
			7 P.M.	weight 2 grains.	38 2	76		·603		
29.	−26 12	336 12	11 A.M.	S.	41 37	79		·604		
			to	N.	34 0	79		·605		
			1 P.M.	S. and N.	58 44	79		·603		
			to	weight 2 grains.	37 46	79	S.E. by E.	·601	·604	·829
				weight 2 grains.	37 45	79		·601		
			3 P.M.	weight 1 grain.	17 46	79		·607		
				weight 1 grain.	17 49	79		·606		
30.	−27 4	337 22	10 A.M.	S.	41 24	79		·611		
			to	N.	33 56	79		·606		
			Noon.	S. and N.	58 50			·602		
	−27 5	337 28	0 15	weight 1 grain.	17 55	77	S.E.	·597	·606	·832
			to	weight 1 grain.	17 50			·600		
				weight 2 grains.	37 16	77		·614		
			1 40 P.M.	weight 2 grains.	37 18			·613		

Table I. (Continued.)

1839.	Position. Lat.	Position. Long. E.	Time of day.	Method employed.	Deflection observed.	Thermometer.	Ship's head.	Intensity. London = 1·000.		Intensity. = 1·372.
	° ′	° ′	h m		° ′	°				
Dec. 31.	−27 43	338 34	10 A.M.	S.	41 27	78	S.E. by E. ½ E.	·610		
			to	N.	34 12	78		·600		
			Noon.	S. and N.	58 50	78		·602	·607	·833
	−27 44	338 40	2 P.M.	weight 2 grains.	36 47	76	E.S.E.	·620		
			3 P.M.	weight 1 grain.	17 48	76		·601		
1840. Jan. 1.			10 30 A.M.	S.	41 39	77		·604		
			11 A.M.	N.	34 5			·603		
			11 30 A.M.	S. and N.	58 56		E. by S.	·599	·603	·828
	−28 19	340 10	Noon.	weight 1 grain.	17 52			·598		
			0 30 P.M.	weight 2 grains.	37 20			·612		
2.	−28 5	341 39	9 30 P.M.	S.	41 49	76		·600		
			10 00 P.M.	N.	33 59			·605		
			10 30 P.M.	S. and N.	59 0			·598		
			11 0 P.M.	weight 1 grain.	17 56	76	E.N.E.	·596	·603	·828
	−27 57	341 50	Noon.	weight 1½ grain.	27 7			·605		
			1 P.M.	weight 2 grains.	37 36			·609		
3.	−27 26	342 29	9 30 A.M.	S.	41 31			·607		
			10 0 A.M.	N.	33 58		N.E. by E.	·606	·605	·830
			10 40 A.M.	S. and N.	58 45			·603		
4.	−26 51	342 56	9 30 A.M.	S.	41 32			·607		
			10 0 A.M.	N.	34 5			·603		
			10 30 A.M.	S. and N.	58 59		N.E. by N.	·598	·601	·824
			11 30 A.M.	weight 1 grain.	18 2			·593		
	−26 42	343 0	Noon.	weight 2 grains.	38 7			·602		
5.			11 A.M.	S.	41 37		N.N.E.	·605		
			11 30 A.M.	N.	34 23		N. by E. ½ E.	·596		
	−25 39	342 57	Noon.	S. and N.	59 1			·598	·600	·823
			1 P.M.	weight 1 grain.	18 7	76		·590		
			2 P.M.	weight 1½ grain.	26 40		N.N.E.	·615		
	−25 29	342 58	3 P.M.	weight 2 grains.	38 20			·599		
6.			11 30 A.M.	S.	41 52	76	N.N.E.	·599		
	−24 13	343 3	Noon.	N.	34 23			·596		
			0 30 P.M.	S. and N.	59 13			·595	·592	·812
			1 0 P.M.	weight 1 grain.	18 9	76	N.E. by N.	·589		
	−24 6	343 06	3 0 P.M.	weight 1 grain.	18 14			·587		
			5 30 P.M.	weight 1 grain.	18 12			·588		
7.			10½ A.M.	S.	42 2	74		·595		
			11 15 A.M.	N.	34 34	74		·592		
	−22 49	343 35	Noon.	S. and N.	59 23			·593		
			2 30 P.M.	weight 1 grain.	18 7	74	N.E.	·590	·591	·811
			5 30 P.M.	weight 1 grain.	18 20	74	N.E. ½ E.	·584		
	−22 39	343 43	6 0 P.M.	S.	42 3	73		·595		
			6 30 P.M.	N.	34 30			·593		
	−22 34	343 49	7 0 P.M.	S. and N.	59 33			·590		
8.			10½ A.M.	S.	42 10	76	N.E. by E.	·592		
			11 15 A.M.	N.	34 34			·592		
	−21 34	344 15	Noon.	S. and N.	59 39			·589	·590	·810
			2 30 P.M.	weight 1 grain.	18 6	75		·591		
	−21 27	344 19	3 0 P.M.	weight 1 grain.	18 26			·580		
9.	−20 31	345 05	10½ A.M.	S.	42 13		E.N.E.	·591		
			11 15 A.M.	N.	34 36		N.E. by E.	·591		
	−20 24	345 10	Noon.	S. and N.	59 48			·586	·590	·810
			3 P.M.	weight 1 grain.	18 9	74	N.E. ½ E.	·589		
	−20 6	345 22	5 30 P.M.	weight 1 grain.	18 7		N.E. by E. ½ E.	·590		
10.			10 30 A.M.	S.	42 0	76	N.E. ½ E.	·596		
			11 15 A.M.	N.	34 7			·602		
	−18 57	345 45	Noon.	S. and N.	59 9			·595	·595	·817
			0 30 P.M.	weight 1 grain.	18 3	75	N.N.E. ½ E.	·592		
	−18 49	345 48	3 P.M.	weight 1 grain.	18 6	75	N.E.	·591		

Table I. (Continued.)

1840.	Position.		Time of day.	Method employed.	Deflection observed.	Thermometer.	Ship's head.	Intensity.			
	Lat.	Long. E.						London = 1·000.			= 1·372.
	° ′	° ′	h m		° ′	°					
Jan. 11.	−17 39	346 10	10 30 A.M.	S.	41 54	78	N.E. by E.	·598			
			11 35 A.M.	N.	34 0		N.N.E.	·605			
	−17 33	346 13	Noon.	S. and N.	59 10		N.E. by E.	·595	·597		·820
			3 P.M.	weight 1 grain.	18 0	72	E.N.E.	·594			
	−17 19	346 21	6 P.M.	weight 1 grain.	17 57	70	S.	·595			
12.			11 30 A.M.	S.	41 54	76	N.E. by E.	·598			
	−17 11	346 40	Noon.	N.	34 43			·588			
			0 30 P.M.	S. and N.	59 7			·596	·595		·817
			2 P.M.	weight 1 grain.	17 55		S.	·597			
13.			11 0 A.M.	S.	42 9		E. by N.	·592			
			11 30 A.M.	N.	34 20		N.E.	·597			
	−16 35	347 13	Noon.	S. and N.	59 18		E. by N.	·593			
			2 P.M.	weight 1 grain.	17 58	74	N.E.	·595	·594		·816
			2 30 P.M.	weight 1 grain.	17 59			·595			
	−16 25	347 22	3 30 P.M.	weight 1½ grain.	27 43			·592			
14.			10 30 A.M.	S.	42 6	76	N.E. by E. ½ E.	·594			
			11 15 A.M.	N.	34 22			·596			
	−15 19	348 0	Noon.	S. and N.	59 9			·596	·598		·821
			2 30 P.M.	weight 1 grain.	17 55			·597			
	−15 12	348 02	3 00 P.M.	weight 1½ grain.	27 6			·606			
15.			11 30	S.	42 18			·589			
	−15 20	348 07	Noon.	N.	34 30			·593	·592		·813
			0 30 P.M.	S. and N.	59 21			·594			
16.			10 30 A.M.	S.	41 53		S.S.W.	·598			
			11 15 A.M.	N.	34 20			·597			
	−15 49	348 09	Noon.	S. and N.	58 53			·600			
			1 P.M.	weight 1 grain.	17 56	76		·596	·599		
				weight 1 grain.	17 50			·599			
				weight 2 grains.	38 16			·600			
				S.	42 26		E. by N. ¼ N.	·585		·594	·815
				N.	34 49			·587			
				S. and N.	59 22			·593			
				weight 1 grain.	18 14	76		·587	·590		
				weight 1 grain.	18 7			·590			
				weight 2 grains.	38 31			·597			
17.			3 P.M.	S.	42 19		E.	·588			
	−15 30	348 51	3 30 P.M.	N.	35 4			·582			
			4 0 P.M.	S. and N.	59 38			·589	·589		·810
				weight 1 grain.	18 0			·594			
18.	−14 37	349 30	9 30 A.M.	S.	42 12		N.E. by E.	·591			
			11 A.M.	S.	41 53		S. by W.	·598			
			11 20 A.M.	S.	42 0		S.W. by W.	·596			
			11 40 A.M.	S.	41 51		N. by E.	·599			
	−14 36	349 31	Noon.	S.	41 57		N.E. by E.	·596			
			0 30 P.M.	N.	34 30			·593	·595		·816
			1 0 P.M.	S. and N.	59 31			·591			
	−14 31	349 39	2 0 P.M.	weight 1 grain.	17 55	76		·597			
			2 30 P.M.	weight 1 grain.	17 56			·596			
			3 P.M.	weight 2 grains.	38 25			·598			
	−14 27	349 50	4 P.M.	weight 2 grains.	38 28			·597			
19.	−13 39	350 29	Noon.	S.	42 1		E. by N.	·596			
			3 P.M.	S.	41 52		S. by W. ½ W.	·598	·599		·822
	−13 35	350 36	2 P.M.	weight 1 grain.	17 41	76	S.S.W.	·604			
20.			10 30 A.M.	S.	42 28		E. ¼ N.	·584			
			11 15 A.M.	N.	34 19			·597			
	−14 19	350 33	Noon.	S. and N.	59 29			·591	·592		·813
				weight 1 grain.	17 55			·597			

TABLE I. (Continued.)

1840.	Position. Lat.	Position. Long. E.	Time of day.	Method employed.	Deflection observed.	Thermometer.	Ship's head.	Intensity. London = 1·000.		Intensity. = 1·372.
	° ′	° ′	h. m.		° ′	°				
Jan. 21.	−14 51	350 31		S.	42 16		W.	·589	·594	·815
				S.	42 7		N.W.	·593		
				S.	41 44		N.	·601		
				S.	42 6		N.E.	·593		
				S.	42 15		E.	·589		
				weight 1 grain.	17 52			·598		
22.			11 A.M.	S.	41 51	75	S.W.	·599	·601	·825
	−14 8	351 31	Noon.	weight 1 grain.	17 41			·604		
				S.	41 52		N.E.	·598		
				weight 1 grain	17 45	67		·601		
23.			11 A.M.	S.	41 46			·601	·600	·823
	−13 43	352 01	Noon.	weight 1 grain.	17 50	70	S. by W. ½ W.	·599		
24.			10 30 A.M.	S.	41 47			·601	·601	·825
			11 A.M.	N.	33 54			·607		
	−14 26	351 57	Noon.	S. and N.	58 36			·605		
			0 15 P.M.	weight 1 grain.	17 54	77	S.	·597		
				weight 1 grain.	17 56			·596		
25.			10 15 A.M.	S.	41 47	77	S. by W.	·601	·601	·825
	−15 3	351 54	Noon.	N.	33 59			·605		
				S. and N.	58 44			·603		
			0 30 P.M.	weight 1 grain.	17 57	77		·596		
26.			11 A.M.	S.	41 51	78	S. by W.	·599	·597	·819
	−15 23	352 6	Noon.	weight 1 grain.	17 59			·595		
27.	−15 17	352 35	10 A.M.	S.	41 54	77	S.	·598	·598	·820
			11 A.M.	weight 1 grain.	17 55			·597		
28.	−15 19	353 13	10 A.M.	S.	42 1	76	E.N.E.	·595	·598	·820
				weight 1 grain.	17 48			·601		
29.			10 30 A.M.	S.	41 40	78	S.S.W.	·604	·604	·829
	−15 7	353 44	Noon.	weight 1 grain.	17 40			·605		
30.			11 0 A.M.	S.	41 46	77	S. ½ W.	·601	·601	·825
	−15 5	354 8	Noon.	weight 1 grain.	17 48		S. by W.	·601		
Feb. 3.	−15 55	354 17		S.	41 26		Observed on shore.	·610	·611	·838
	Sister's Walk, James Town. St. Helena.			S. and N.	58 18			·610		
				N.	33 45			·611		
				weight 1 grain.	17 43	81		·603		
				weight 1½ grain.	26 36			·617		
				weight 2 grains.	37 13			·615		
5.	Longwood. St. Helena.			S.	42 35		Observed on shore.	·581	·586	·804
				S. and N.	59 56			·584		
				N.	34 53			·585		
				weight 1 grain.	18 13	69·7		·587		
				weight 1½ grain.	27 17			·601		
				weight 2 grains.	39 52			·579		
6.	St. Helena.		1 P.M.	S.	42 23	79	W.	·586	·591	·811
				S.	42 26		N.W.	·585		
				S.	41 47		N.	·601		
				S.	41 52		N.E.	·599		
				S.	42 20		W.	·587		
				S.	42 0		S.W.	·595		
				S.	42 19		S.	·587		
				S.	42 11		S.E.	·592		
				S.	42 19		E.	·587		
10.	−17 22	353 30	11 30 A.M.	S.	41 49	77	S.S.W. ½ W.	·601	·600	·823
	−17 30	353 26	5 P.M.	S.	41 51	74	S.W. ½ S.	·599		
11.			11 A.M.	S.	41 51		S.S.W. ½ W.	·599	·603	·827
	−18 46	352 46	Noon.	weight 1 grain.	17 32	76		·609		
			4 P.M.	S.	41 46			·601		
	−19 1	352 44	4 30 P.M.	S.	41 43			·603		

TABLE I. (Continued.)

1840.	Position.		Time of day.	Method employed.	Deflection observed.	Thermometer.	Ship's head.	Intensity.		
	Lat.	Long. E.						London = 1·000.		= 1·372.
	° ′	° ′	h m		° ′	°				
Feb. 12.	−20 41	352 0		S.	41 56	77	s.s.w.	·597		
				S and N.	58 41			·604		
				N.	34 29	76		·594		
			Noon.	weight 1 grain.	17 28	76	s.s.w. ½ w.	·612	·600	·823
			1 12 P.M.	weight 1 grain.	17 36			·607		
			1 30 P.M.	S.	41 57			·597		
			6 P.M.	S.	41 2	74	s.w. ½ w.	·597		
	−21 1	351 49	6 30 P.M.	S.	41 4	72	s.w. by s.	·596		
13.	−21 52	351 31	10 A.M.	S.	40 57	72	s. by E.	·599		
			10 30	S.	40 57	75		·599		
			10 45	S. and N.	57 34	76		·599	·599	·821
			11 0	N.	34 1			·605		
			11 30	S.	41 0	77	s.	·598		
	−22 12	351 23	Noon.	weight 1 grain.	18 1			·594		
			1 0 P.M.	weight 1 grain.	18 0	74	s. by w.	·594		
	−22 19	351 22	3 0	S.	41 4	74		·596		
	−22 23	351 22	5 0	S.	41 11	74		·594	·596	·818
			5 20	S.	41 5			·595		
			6 30	S.	40 56	73		·599		
14.	−23 33	351 10	7 A.M.	S.	40 41		s.s.w.	·604		
			8 30	S.	40 58	77	w.	·599		
	−23 37	351 0	9 30	S.	41 0			·595	·599	·821
			10 0	S. and N.	57 45			·597		
			10 40	N.	34 12			·599		
	−23 42	350 44	Noon.	weight 1 grain.	17 56			·596		
			1 30 P.M.	S.	40 58	78	E.	·599		
	−23 47	350 28	3 0	S.	41 5	76	w.	·595	·596	·818
			4 0	weight 1 grain.	18 0	75		·594		
	−23 51	350 16	5 30	S.	41 4	74		·596		
15.	−24 31	348 48	9 A.M.	S.	41 7	77	w.	·595		
			10	weight 1 grain.	17 50	78		·600		
			10 30	weight 1 grain.	17 51	78		·599	·596	·818
			11 00	S.	41 12	80		·594		
			11 30	S.	41 4	80		·596		
	−24 36	348 30	Noon.	S.	41 10	81		·595		
	−24 39	348 20	2 30 P.M.	S.	41 2	77		·597		
	−24 42	348 17	4 0	weight 1 grain.	17 45	74		·602		
			5 20	weight 1 grain.	17 45	75		·602		
	−24 42	348 10	6 0	S.	40 59	75		·598	·598	·820
			7 0	S.	41 12	74		·594		
	−25 0	348 0	Midnight.	S.	41 4	73		·596		
			0 40	weight 1 grain.	17 56	73	s.w.	·596		
16.	−25 15	347 59	6 A.M.	weight 1 grain.	17 51	72		·599		
			7	S.	40 49	73		·601		
			11	S.	40 57	80		·599	·598	·820
			11 30	S. and N.	58 13			·591		
	−25 24	347 49	Noon.	N.	34 9			·602		
			0 30 P.M.	weight 1 grain.	17 47	81		·602		
			1 0	weight 1½ grain.	27 18			·602		
			1 30	weight 2 grains.	38 11			·601	·605	·829
	−25 38	347 41	6 0	S.	40 13	76	s.w. by s.	·613		
			6 30	weight 1 grain.	17 36			·607		
17.	−26 8	347 03	10 A.M.	S.	40 50	77	w.	·601		
			10 30	S.	41 10	78	E.	·594	·602	·826
	−26 8	347 03	5 P.M.	S.	40 24	75	s. by E.	·609		
18.	−27 0	346 33	10 A.M.	S.	40 20	78	s.s.w.	·611		
			10 40	S. and N.	57 11			·605		
			11 20	N.	33 19			·621	·615	·844
	−27 6	346 32	Noon.	weight 1 grain.	17 7			·624		

Table I. (Continued.)

1840.	Position.		Time of day.	Method employed.	Deflection observed.	Thermometer.	Ship's head.	Intensity.		
	Lat.	Long. E.						London = 1·000.		= 1·372.
	° ′	° ′			° ′	°				
Feb. 19.	−27 55	346 41	10 A.M.	S.	40 28	78	S.E.	·610		
			10 30	weight 1 grain.	17 27			·612		
			11 10	weight 1½ grain.	27 20			·601	·607	·834
	−27 57	346 46	Noon.	weight 2 grains.	37 47			·607		
20.			10 30 A.M.	S.	40 17	77	S.E.	·612		
			11 10	S. and N.	57 34			·599		
			11 40	N.	33 26			·618	·609	·836
	−28 57	348 32	Noon.	weight 1 grain.	17 29	79		·611		
	−29 8	349 0	5 P.M.	S.	40 35			·606		
21.	−30 1	351 29	9 30 A.M.	S.	40 1		S E.	·618		
			10	weight 1 grain.	16 58			·629	·622	·852
	−30 28	351 45	5 30 P.M.	S.	40 1		S.E. ½ E.	·618		
22.	−30 59	353 23	7 A.M.	S.	39 48			·621		
	−31 7	353 46	10	S.	39 48			·621		
			10 30	S. and N.	57 7			·605		
			11 00	N.	32 51			·632	·619	·849
			11 30	weight 1 grain.	17 25			·610		
	−31 10	354 0	Noon.	weight 1½ grain.	26 27			·619		
	−31 17	354 34	4 40 P.M.	S.	39 32			·627		
23.	−31 46	356 38	11 30 A.M.	S.	39 4		S.E. by E.	·636		·872
24.	−31 13	358 38	10 A.M.	S.	39 9		E. ½ S.	·635		
			10 30	S.	39 7		E. by S.	·635	·636	·872
			11 00	weight 1 grain.	16 43			·638		
25.	−30 17	359 40	6 A.M.	S.	39 12		E.	·634		
			6 30	weight 1 grain.	17 1			·627		
			7 0	weight 1 grain.	17 0			·628		
	−30 18	359 55	10 0	S.	38 20		S.E.	·652	·640	·878
			10 40	N.	32 6			·652		
			11 10	S. and N.	55 37			·630		
	−30 14	359 55	Noon.	weight 1 grain.	16 29			·647		
	−30 30	359 48	5 30 P.M.	S.	38 22		S.W.	·653		
26.	−31 7	359 27	10 A.M.	S.	38 7		S. ½ W.	·658		
			10 20	S. and N.	55 16			·636		
			10 45	N.	32 3		S. by W.	·653		
			11 10	weight 1 grain.	16 50			·634	·647	·888
			11 40	S.	38 5		S.W.	·658		
	−31 9	359 24	Noon.	S.	38 31		W.	·644		
27.	−31 18	359 48	10 A.M.	S.	38 36	71	S.E.	·645		
			10 30	S. and N.	55 27			·633		
			11 20	N.	32 13			·649	·638	·876
	−31 20	359 57	Noon.	weight 1 grain.	17 0			·627		
28.	−32 1	2 17	10 30 A.M.	S.	38 33	72	S.E.	·645	·645	·886
			11 0	S.	38 34			·645		
29.	−32 39	4 18	11 A.M.	S.	37 43	70	S.E.	·666		·915
March 1.	−33 9	5 48	11 00	S.	37 52·5	71	S.E.	·663		
			11 30	S. and N.	54 3·5	71		·657	·665	·913
			Noon.	N.	31 16	71		·674		
2.	−33 23	7 41	6 40 A.M.	S.	37 39·7	70		·667		
			11 0	S.	37 23·8	71		·672		
	−33 27	7 20	5 0 P.M.	S.	37 27·7	71		·671		
			5 15	S. and N.	53 10·5	71	S.E. ½ E.	·674	·672	·922
			5 30	N.	30 52·5	71		·686		
			5 50	weight 1 grain.	15 56·2	70		·667		
			6 15	weight 1 grain.	15 57·8	70		·668		
3.	−33 21	9 4	3 40 P.M.	S.	37 12		W.S.W.	·678	·675	·925
			4 30	S.	37 28		E.N.E.	·671		

Table I. (Continued.)

1840.	Position. Lat.	Position. Long. E.	Time of day.	Method employed.	Deflection observed.	Thermometer.	Ship's head.	Intensity. London = 1·000.		= 1·372.
	° ′	° ′	h m		° ′	°				
March 4.	−33 8	10 11	10 0 A.M.	S.	37 16·7	66		·677		
			10 30	N. and S.	53 20			·670		
			11 0	N.	31 1·5		S.E.	·681	·679	·932
			Noon.	weight 1 grain.	15 28	67		·687		
5.	−33 11	11 57	6 30 A.M.	S.	37 11	68	E.S.E.	·678		
			9 30	S.	37 11·7	68	S.E. ½ S.	·678	·682	·935
			11 0	weight 1 grain.	15 30·2	68	S.E.	·686		
			11 30	weight 1 grain.	15 32·2			·685		
6.	−32 57	14 00	10 A.M.	S.	36 39·5	69	S.E. by E.	·691		·947
7.	−32 33	15 24	3 15 P.M.	S.	36 25·4	72	E.S.E.	·697		·956
8.	−32 17	17 0	Noon.	S.	36 13	68	S.E. ½ S.	·702		·963
9.	−32 31	17 41	Noon.	S.	36 33·2	61	W. by N. ½ N.	·693		·951
10.	−32 45	16 37	0 30 P.M.	S.	36 29·5	63	S.E.	·694		·952
11.	−33 3	16 46	10 0 A.M.	S.	36 2·4			·707		·970
12.	−33 17	16 51	10 0 A.M.	S.	35 54·2	69	S.E. by S.	·711		
			10 30	S.	35 47·2	69		·713		
	−33 17	17 00	3 P.M.	S.	35 55·5	72		·711		
			3 30	S. and N.	50 56·6	72		·719	·720	·988
			3 50	N.	29 19·5	72	S. by E. ½ E.	·733		
			4 10	weight 1 grain.	14 36·7	71		·727		
			4 30	weight 1 grain.	14 42	71		·723		
13.			10 A.M.	S.	35 20	65		·723		
			10 30	S. and N.	50 57·2	65		·720		
			11 0	N.	29 28	65		·729		
			11 30	weight 1 grain.	14 42·2	64		·722		
	−33 56	18 10	Noon.	weight 1½ grain.	22 0·2	64		·735		
			0 30 P.M.	S.	35 20·2	65	S. by W.	·723	·725	·995
			1 30	S.	35 21	65		·723		
			1 50	S. and N.	50 55·2	66		·720		
			2 10	N.	29 26	66		·730		
			2 30	weight 1 grain.	14 40·3	66		·724		
14.	−34 20	17 57	10 A.M.	S.	35 38·9	61	E.S.E.	·715		·981
17.			10 A.M.	S.	35 34·5	71		·717		
			10 20	S. and N.	51 9·7	71		·715		
			10 40	N.	29 37·7	71	S.E.	·724		
			0 30 P.M.	weight 1 grain.	14 39·7	71		·724		
			1 0	weight 1 grain.	14 34·2	71		·729	·716	·982
				S.	35 46·2		N.E.	·712		
				S.	36 1·5		E.N.E.	·706		
				S.	35 59·5		E.	·706		
				S.	35 53·2		E.S.E.	·710		
18.	Single Anchor,			S.	35 39·4		S.E.	·715		
	Simon's Bay.			S.	35 17			·724		
19.	Moored in Si-			S.	35 47·6		E.S.E.	·711		
	mon's Bay.			S.	35 35		S.S.E.	·717		
				S.	35 25·8		S.	·721		
				S.	35 1		S.S.W.	·733		
			Noon.	S.	34 56·2		S.W.	·735		
				S.	35 45		W.S.W.	·713		
				S.	35 24		W.	·722		
				S.	35 31·8		W.N.W.	·718		
				S.	35 35		N.W.	·717		
				S.	35 24·8		N.N.W.	·722		
			4 P.M.	S.	35 26·3		N.	·721		
			6 P.M.	S.	35 39·2		N.N.E.	·715		
20.	Admiral's jetty.			S.	35 39·7	79	On shore.	·715		·981

Table I. (Continued.)

1840.	Position. Lat.	Position. Long. E.	Time of day.	Method employed.	Deflection observed.	Thermometer.	Ship's head.	Intensity. London = 1·000.		Intensity. = 1·372.
				S.	35° 09′·1	79°	s.	·729		
March 20.	Moored in Simon's Bay.			S.	35 16·2	76	s.w.	·726		
				S.	35 39·1		w.	·715		
	34 11	18 26		S.	35 50·7		N.W.	·710		
				S.	35 45·6		N.	·712		
				S.	35 48·9		N.E.	·711		
				S.	35 38·6		E.	·715		
	Block House Simon's Bay.			S.	35 39·3	80·5	Observed on shore.	·715	·715	·981
				S. and N.	51 06·4	80·5		·716		
			Noon.	N.	29 54·2	80·5		·714		
				weight 1 grain.	14 48·9	87·5		·719		
				weight $1\frac{1}{2}$ grain.	22 57·8	87·5		·709		
25.			8 A.M.	S.	35 40·8	80·5		·715		
				S. and N.	51 13·5	80·5		·714		
				N.	29 51·5	80·5		·716		
				weight 1 grain.	15 20·6	92		·695*		
				weight $1\frac{1}{2}$ grain.	22 42·4	91		·715		

Observations in the Terror.—The observations in the Terror were made with a Fox's needle of four inches diameter; one of equal size with that in the Erebus, which was not ready when the Expedition sailed, having been sent out subsequently, and received by Captain Crozier, at Van Diemen Island, in August 1840. An instrument of only two inches radius, for the purpose of determining both the dip and intensity at sea, might previously have been regarded by many persons as scarcely more than a philosophical toy; and as little likely to yield results having the precision which is now required in such determinations. It has, however, in Captain Crozier's hands, fully justified the expectations which Mr. Fox, from his own experiments with it, had ventured to entertain. On land, the instruments of the Erebus and Terror are, for the most part, as far as they have yet reached us, nearly identical in their results. Confining our attention to the *intensity* as the subject immediately before us, the intensities at James Town in St. Helena, and at Longwood in the same island, measured by the instruments of the two ships, the days and spots of observation being the same, are by the Erebus in the proportion of ·586 at Longwood to ·611 at James Town, and by the Terror as ·587 to ·611. The agreement is in this case the more valuable, because we are justified by it in ascribing the difference thus found between places so geographically near to each other, to a really existing difference (viz. to station error), rather than to accident or to observation error, as might have been done, had only a single instrument been used. A similar accord in the determinations of the two instruments is shown by the results at the Cape of Good Hope and Kerguelen Island, which, though more properly belonging to the next section, may be instanced here in evidence of the confirmation which the two instruments

* Omitted in the mean.

mutually afford each other; the Erebus making the intensity on shore at Christmas Harbour, in Kerguelen Island, to be as 1·068 to 0·715 at Simon's Bay, and the Terror as 1·0675 to 0·715. At sea, where in consequence of the motion of the ship, the inferior size of the four-inch instrument cannot be compensated by additional time given to the reading, or by other arrangments conducing to minute accuracy, the probable error of a single result appears, as might be expected, to be somewhat greater with the four inch-than with the $7\frac{1}{2}$-inch needle; but, with this reservation, the observations made at sea with the two instruments, when the ships were in company, are highly confirmatory each of the other.

The table which has been received from the Terror contains almost daily observations from the 1st of January 1840 until her arrival at the Cape of Good Hope in the following March. The intensities were observed both by deflectors and by constant weights, which latter, in the four-inch instrument, were ·5 and ·3 of a grain. St. Helena is the only land station observed at in the passage; the intensities observed at sea have therefore been computed relatively to the observations at James Town St. Helena, taken as a base station; and the value of the intensity at James Town has been taken as determined by the Erebus, viz. as 0·611, to unity in London, or as 0·838 to 1·372 in London. The values of w' for the Terror's deflectors N. and S, required, instead of a table of coercing weights, in computing the intensities when the deflectors were used, have been derived by the method already explained. Tables of these values for each degree of deflection are subjoined: neither on a careful examination of the observations, nor in the process of forming these tables, does there appear any reason to suppose that the deflectors or the needle sustained any change in magnetic condition during the period embraced by the observations under notice.

Values of w', Terror's Deflectors.	
N.	S.
° gr.	° gr.
38 = ·837	33 = ·732
39 = ·828	34 = ·726
40 = ·819	35 = ·721
41 = ·811	36 = ·716
42 = ·803	37 = ·711
43 = ·797	38 = ·707
44 = ·7925	39 = ·703
45 = ·791	40 = ·700
46 = ·7895	
47 = ·7885	

With the values of w' taken from this Table, the intensities at sea are obtained relatively to 0·611 at St. Helena (London = 1), by the formula

$$I' = \cdot 5393\, w' \operatorname{cosec} v'.$$

Table II.

Observations of the Magnetic Intensity on Shore, and on Board Her Majesty's Ship Terror, with a four-inch Fox's Needle.

1840.	Position.		Time of day.	Method employed.	Deflection observed.	Thermometer.	Ship's head.	Intensity.		
	Lat.	Long. E.						London = 1·000.		= 1·372.
	° ′	° ′	h m		° ′	°				
Jan. 1.	−28 17	339 59	9 25 A.M.	N.	46 27	77	E.S.E.	·587	·591	·812
				S.	38 54	77		·604		
				weight ·5 grain.	26 50·5	77		·597		
				weight ·3 grain.	16 20·0	77		·575		
2.	−28 03	341 41	9 50 A.M.	N.	46 02·1	76	E. ½ N.	·593	·587	·808
				S.	39 57·0	76		·588		
				weight ·5 grain.	27 31·0	76		·583		
				weight ·3 grain.	16 08·0	76		·582		
2.	−27 48	341 53	5 0 P.M.	N.	45 35	76	N.E. ½ E.	·596	·597	·820
				S.	38 57	76		·603		
				weight ·5 grain.	27 18·5	76		·587		
				weight ·3 grain.	15 33	76		·603		
3.	−27 26	342 28	9 40 A.M.	N.	45 40	76	N.E. by E.	·595	·595	·817
				S.	39 01	76		·602		
				weight ·5 grain.	27 20	76		·587		
				weight ·3 grain.	15 41	76		·598		
4.	−26 50	342 58	9 40 A.M.	N.	45 03	76	N.E.	·602	·600	·824
				S.	39 03	76		·601		
				weight ·5 grain.	26 55	76		·595		
				weight ·3 grain.	15 33	76		·603		
5.	−25 50	342 55	10 00 A.M.	N.	45 25	76	N.E. by N.	·598	·603	·828
				S.	39 07·5	76		·600		
				weight ·5 grain.	26 18	76		·607		
				weight ·3 grain.	15 28	76		·607		
6.	−24 28	343 0	9 50 A.M.	N.	45 27	76		·598	·593	·815
				S.	39 26	76		·596		
				weight ·5 grain.	26 27	76		·605		
				weight ·3 grain.	16 27	76		·571		
7.	−22 56	343 30	10 00 A.M.	N.	45 34	73	N.E. ½ N.	·596	·594	·816
				S.	40 10	73		·585		
				weight ·5 grain.	26 57	73		·594		
				weight ·3 grain.	15 34	73		·602		
8.	−21 43	344 13	10 0 A.M.	N.	46 06	76	E.N.E.	·591	·589	·810
				S.	41 05·5	76		·574		
				weight ·5 grain.	26 32	76		·603		
				weight ·3 grain.	16 00·5	76		·586		
9.	−20 31	345 05	9 45 A.M.	N.	46 21	74	E. ½ N.	·588	·583	·800
				S.	40 23	74		·583		
				weight ·5 grain.	27 48	74		·578		
				weight ·3 grain.	16 07	74		·583		
10.	−19 12	345 45	9 00 A.M.	N.	46 04	76	N.N.E.	·591	·593	·815
				S.	40 02	76		·587		
				weight ·5 grain.	26 39	76		·600		
				weight ·3 grain.	15 40	76		·593		
11.	−17 44	346 10	10 00 A.M.	N.	45 51·5	78	N.E.	·594	·594	·816
				S.	39 48	78		·590		
				S.	39 21	78		·597		
				weight ·5 grain.	26 51	78		·595		
				weight ·3 grain.	15 47·5	78		·594		
12.	−17 23	346 29	9 00 A.M.	N.	46 05	76	N.E. by E. ½ E.	·591	·593	·815
				S.	40 25	76		·583		
				weight ·5 grain.	26 53	76		·596		
				weight ·3 grain.	15 38	76		·600		

TABLE II. (Continued.)

1840.	Position. Lat.	Position. Long. E.	Time of day.	Method employed.	Deflection observed.	Thermometer.	Ship's head.	Intensity. London = 1·000.		= 1·372.
	° ′	° ′	h m		° ′	°				
Jan. 13.	−16 43	347 02	10 0 A.M.	N.	45 56	74	E. ½ N.	·593	·592	·812
				N.	45 39	74		·595		
				S.	39 32	74		·594		
				S.	39 45	74		·591		
				weight ·5 grain.	27 07	74		·591		
				weight ·3 grain.	15 55·5	74		·590		
14.	−15 25	347 50	9 40 A.M.	N.	46 50	76	E.N.E.	·583	·595	·816
				S.	39 17	76		·598		
				weight ·5 grain.	27 01	76		·593		
				weight ·3 grain.	15 26	76		·608		
15.	−15 30	347 58	9 10 A.M.	N.	46 18	76	N.E. by E.	·588	·598	·820
				S.	39 04	76		·601		
				weight ·5 grain.	27 20	76		·586		
				weight ·3 grain.	15 12	76		·617		
16.	−15 41	348 09	9 10 A.M.	N.	45 26	76	S.W. by S.	·598	·617	·847
				S.	38 12	76		·616		
				weight ·5 grain.	25 54	76		·616		
				weight ·3 grain.	14 40·5	76		·638		
17.	−15 37	348 32	9 45 A.M.	N	46 25	76	E. by N.	·587	·597	·818
				S.	39 43	76		·591		
				weight ·5 grain.	26 27	76		·604		
				weight ·3 grain.	15 32	76		·604		
18.	−14 45	349 22	9 45 A.M.	N.	46 10	76		·590	·598	·820
				S.	39 24	76		·596		
				weight ·5 grain.	26 40	76		·599		
				weight ·3 grain.	15 24	76		·609		
19.	−13 44	350 20	9 15 A.M.	N.	45 19	76		·599	·604	·829
				S.	39 01	76		·602		
				weight ·5 grain.	26 52	76		·595		
				weight ·3 grain.	15 08	76		·619		
20.	−14 28	350 19	9 20 A.M.	N.	45 39	76	S.W. ½ W.	·595	·605	·830
				S.	38 49	76		·605		
				weight ·5 grain.	26 31	76		·603		
				weight ·3 grain.	15 09	76		·619		
20.	−14 26	350 21	10 15 A.M.	N.	46 26	76	E.	·587	·602	·826
				S.	39 29	76		·595		
				weight ·5 grain.	27 14	76		·588		
				weight ·3 grain.	14 50	76		·637		
21.	−14 54	350 25	8 50 A.M.	N.	46 09	76	S.W. by S.	·590	·609	·836
				S.	39 04	76		·601		
				weight ·5 grain.	25 59	76		·614		
				weight ·3 grain.	14 51	76		·631		
21.	−14 53	350 26	9 50 A.M.	N.	46 06	76	E.N.E.	·591	·594	·815
				S.	39 14	76		·598		
				weight ·5 grain.	27 15	76		·588		
				weight ·3 grain.	15 36	76		·601		
22.	−14 08	350 28	9 40 A.M.	N.	45 23	76	S.W. by S.	·598	·609	·836
				S.	38 59	76		·602		
				weight ·5 grain.	26 05·5	76		·612		
				weight ·3 grain.	14 58	76		·626		
23.	−13 36	352 0	9 45 A.M.	N.	45 32	76		·597	·607	·834
				S.	38 37	76		·609		
				weight ·5 grain.	26 39	76		·600		
				weight ·3 grain.	15 07	76		·620		
24.	−14 19	351 53	9 10 A.M.	N.	45 21	76	S. ½ W.	·599	·608	·835
				S.	38 19	76		·613		
				weight ·5 grain.	26 33	76		·602		
				weight ·3 grain.	15 08	76		·619		

Table II. (Continued.)

1840.	Position. Lat.	Position. Long. E.	Time of day.	Method employed.	Deflection observed.	Thermometer.	Ship's head.	Intensity. London = 1·000.		Intensity. = 1·372.
	° ′	° ′	h m		° ′	°				
Jan. 25.	−14 55	351 52	9 15 A.M.	N.	45 36	77	S.S.W.	·596		
				S.	38 40	77		·608	·604	·829
				weight ·5 grain.	26 39	77		·600		
				weight ·3 grain.	15 21	77		·611		
26.	−15 14	352 03	9 15 A.M.	N.	45 08	77		·601		
				S.	38 32	77		·610	·605	·830
				weight ·5 grain.	26 25	77		·607		
				weight ·3 grain.	15 31	77		·604		
27.	−15 11	352 32	9 15 A.M.	N.	45 31·5	77	E.N.E.	·597		
			9 15	S.	38 27	77		·611	·601	·825
			9 15	weight ·5 grain.	26 33	77		·602		
			9 15	weight ·3 grain.	15 45	77		·595		
27.	−15 13	352 33	10 20 A.M.	N.	45 0	77	S. ½ W.	·603		
				S.	38 41	77		·608	·611	·838
				weight ·5 grain.	25 40	77		·621		
				weight ·3 grain.	15 18·5	77		·612		
28.	−15 19	353 6	9 40 A.M.	N.	45 17	76	S.S.W.	·600		
				S.	38 30	76		·610	·607	·834
				weight ·5 grain.	26 29	76		·603		
				weight ·3 grain.	15 30	76		·615		
28.	−15 20	353 07	10 40 A.M.	N.	45 29	76	E.N.E.	·597		
				S.	39 02	76		·602	·604	·829
				weight ·5 grain.	25 56	76		·604		
				weight ·3 grain.	15 18	76		·613		
29.	−15 00	353 36	9 30 A.M.	N.	45 58	78	N.E. by E.	·592		
				S.	39 14	78		·599	·597	·818
				weight ·3 grain.	15 36	78		·601		
29.	−15 02	353 36	10 45 A.M.	N.	45 39	78	S. ½ W.	·595		
				S.	38 28	78		·611	·600	·824
				weight ·5 grain.	26 19·5	78		·607		
				weight ·3 grain.	15 58	78		·588		
30.	−15 10	354 5	10 10 A.M.	N.	45 47	77	S.S.W.	·594		
				S.	38 37	77		·609	·608	·835
				weight ·5 grain.	26 12	77		·609		
				weight ·3 grain.	15 10	77		·618		
31.	−15 40	354 19	9 15 A.M.	N.	45 03	78	S. by W.	·603		
				S.	39 17	78		·598	·598	·820
				weight ·5 grain.	27 02·4	78		·592		
				weight ·3 grain.	15 41	78		·598		
Feb. 3.	−15 55	354 17	0 45 P.M.	N.	44 21·2	81	Observed on shore.	·611		
	Sister's Walk, St. Helena.			weight ·5 grain.	26 09·8	81		·611	·611	·838
				weight ·3 grain.	15 21·7	81		·611		
5.	Longwood.			N.	46 07	70		·591		
				weight ·5 grain.	27 10	70		·589		
				weight ·5 grain.	27 06·5	70			·587	·805
				weight ·3 grain.	16 07·1	70		·582		
				weight ·3 grain.	16 06·4	70				
10.	−17 14	353 33	9 40 A.M.	N.	44 42	77	S.W. by S.	·606		
				S.	39 09	77		·600		
				S.	38 47	77		·606	·600	·824
				weight ·5 grain.	26 46	77		·597		
				weight ·3 grain.	15 55	77		·590		
11.	18 33	352 52	9 15 A.M.	N.	45 12	76	S.W.	·601	·601	·825
				S.	39 04	76		·601		
12.	−20 22	352 06	9 20 A.M.	N.	45 10	77	S.S.W. ½ W.	·601		
				S.	38 17	77		·598	·598	·820
				weight ·5 grain.	26 20	77		·607		
				weight ·3 grain.	16 02	77		·585		

Table II. (Continued.)

1840.	Position. Lat.	Position. Long. E.	Time of day.	Method employed.	Deflection observed.	Thermometer.	Ship's head.	Intensity. London = 1·000.			Intensity. = 1·372.
	° ′	° ′	h m		° ′	°					
Feb. 13.	−21 55	351 33	9 10 A.M.	N.	44 52·5	76	s.s.e.				
			9 24 A.M.	N.	45 04·3	76					
	−21 57	351 31	9 55 A.M.	N.	45 03·6	76					
			10 10 A.M.	N.	45 03·2	76				·603	·828
	−22 03	351 30	10 24 A.M.	N.	45 01·2	76					
			10 36 A.M.	N.	45 01·3	76					
	−22 05	351 28	10 55 A.M.	N.	44 58·5	76					
			11 05 A.M.	N.	45 06·2	76					
	−22 07	351 27	1 20 P.M.	N.	45 07·5	76					
			1 35 P.M.	N.	45 03·8	76	s. by w.			·602	·826
	−22 15	351 26	1 55 P.M.	N.	45 03·6	76	s. ½ w.				
			2 10 P.M.	N.	45 10	76					
	−22 20	351 22	5 55 P.M.	N.	45 00·2	74					
			6 10 P.M.	N.	45 00·6	74					
14.	−23 32	350 58	9 00 A.M.	weight ·5 grain.	26 36	77	w.	·601			
				weight ·3 grain.	16 05	77		·584			
				S.	39 02	77		·602			
				N.	45 50	77					
			9 20 A.M.	N.	45 40	77					
	−23 14	350 44	11 35 A.M.	N.	45 46	77			·594	·594	·815
			11 45 A.M.	N.	45 47	77					
	−23 48	350 27	3 40 P.M.	N.	45 52	77					
			4 00 P.M.	N.	45 47	77					
	−23 54	350 13	5 40	N.	45 40	77			·594		
			5 50	N.	45 49	77					
15.	−24 29	348 48	8 50 A.M.	weight ·5 grain.	27 08	77		·590			
			8 50 A.M.	weight ·3 grain.	16 14	77		·579			
			8 50 A.M.	S.	39 43·5	77	w. by s.	·591			
			8 50 A.M.	N.	45 24	77					
			8 58 A.M.	N.	45 26	77					
	−24 31	348 42	10 00 A.M.	N.	45 22	78			·598	·596	·817
			10 15 A.M.	N.	45 29	78					
	−24 35	348 36	11 40 A.M.	N.	45 21	80	w. by n.				
			Noon.	N.	45 32·5	80					
	−24 39	348 24	3 40 P.M.	N.	45 38	76	w.				
			3 50 P.M.	N.	45 41	76			·596		
	−24 41	348 19	5 35 P.M.	N.	45 28	75	w.s.w.				
			5 50 P.M.	N.	45 35	75					
16.	−25 18	347 54	8 50 A.M.	N.	44 41	80	s.s.w.	·606			
			9 20 A.M.	N.	44 41	80		·606			
			9 20 A.M.	S.	38 48	80		·605		·599	·822
			9 20 A.M.	weight ·5 grain.	26 26	80		·605			
			9 20 A.M.	weight ·3 grain.	16 12·5	80		·580			
17.	−26 03	347 07	8 40 A.M.	N.	45 05	77	w.s.w.	·602			
			9 30 A.M.	N.	45 01	77		·603			
			9 30 A.M.	S.	38 45	77		·606		·600	·823
			9 30 A.M.	weight ·5 grain.	26 53	77		·593			
			9 30 A.M.	weight ·3 grain.	15 43·5	77		·597			
18.	−26 51	346 37	9 15 A.M.	N.	44 44·7	78	s.w. by s.	·606			
				S.	38 48·0	78		·605		·604	·829
				weight ·5 grain.	27 13·7	78		·589			
				weight ·3 grain.	15 13·1	78		·616			
19.	−27 54	346 42	9 20 A.M.	N.	44 34·7	78	s.e.	·608			
				S.	38 01·9	78		·619		·607	·834
				weight ·5 grain.	26 28·7	78		·604			
				weight ·3 grain.	15 46·9	78		·595			
20.	−28 47	348 15	9 30 A.M.	N.	44 11·2	77	s.e. ½ s.	·613			
				S.	38 18	77		·614		·615	·844
				weight ·5 grain.	26 02	77		·613			
				weight ·3 grain.	15 08	77		·619			

TABLE II. (Continued.)

1840.	Position. Lat.	Position. Long. E.	Time of day.	Method employed.	Deflection observed.	Thermometer.	Ship's head.	Intensity. London = 1·000.		Intensity. = 1·372.
	° ′	° ′	h m		° ′	°				
Feb. 21.	−29 56	350 42	8 45 A.M.	N.	44 24	79	S.E.	·610	·611	·838
				S.	38 28	79		·611		
22.	−31 00	353 40	9 20 A.M.	N.	43 18·5	79	S.E. ½ E.	·626	·625	·856
				S.	37 39·5	79		·625		
23.	−31 40	356 30	9 10 A.M.	N.	43 29·5	79	S.E. by E.	·622	·626	·857
				S	37 21·1	79		·630		
24.	−31 13	358 26	9 15 A.M.	N.	43 34	79	E. ½ S.	·621	·628	·862
				S.	37 03	79		·635		
25.	−30 10	359 53	9 00 A.M.	N.	43 14	75	E.N.E.	·627	·625	·858
				S.	37 33	75		·627		
				weight ·5 grain.	25 31	75		·625		
				weight ·3 grain.	15 04	75		·622		
25.	−30 12	359 54	10 00 A.M.	N.	43 04	75	S.S.W.	·629	·638	·876
				S.	36 23	75		·647		
26.	−31 07	359 28	9 20 A.M.	N.	42 21	71	S. by W.	·641	·640	·878
				S.	36 18	71		·649		
				weight ·5 grain.	25 21	71		·628		
				weight ·3 grain.	14 32·5	71		·644		
27.	−31 15	359 48	9 10 A.M.	N.	42 45·2	71	S E.	·634	·639	·876
				S.	37 01	71		·636		
				weight ·5 grain.	24 23	71		·651		
				weight ·3 grain.	14 45	71		·634		
28.	−31 57	2 02	9 00 A.M.	N.	42 15·6	72	S.E. ½ S.	·643	·647	·888
				S.	36 11·5	72		·651		
29.	−32 35	4 20	9 40 A.M.	N.	41 29·4	70		·656	·650	·892
				S.	36 33·4	70	S.E.	·644		
March 1.	−33 02	5 40	9 00 A.M.	N.	41 06	71		·664	·670	·919
				S.	34 59	71		·677		
2.	−33 20	7 32	9 10 A.M.	N.	41 01·5	71		·666	·668	·917
				S.	35 19	71		·671		
3.	−33 10	9 02	9 30 A.M.	N.	40 54·5	70	N.E.	·668	·673	·923
				S.	35 09·6	70		·674		
				S.	34 41·8	70		·683		
				weight ·5 grain.	23 39·3	70		·670		
				weight ·3 grain.	13 55·5	70		·673		
4.	−33 03	9 55	9 05 A.M.	N.	40 16·1	67	S.E. ½ S.	·681	·685	·940
				S.	34 24·2	67		·690		
5.	−33 08	11 43	9 15 A.M.	N.	39 45·5	68	S.E. by S.	·693	·698	·957
				S.	33 53·8	68		·702		
6.	−32 56	13 48	9 15 A.M.	N.	39 35·7	70	S.E. by E.	·696	·699	·959
				S.	33 51·1	70		·703		
7.	−32 14	15 20	9 30 A.M.	N.	39 10·5	70	E.S.E.	·705	·707	·970
				S.	32 35·7	70		·709		
8.	−32 16	16 52	9 20 A.M.	N.	39 17·2	68	S.E. ½ S.	·703	·711	·975
				S.	33 12	68		·719		
9.	−32 31	17 45	9 45 AM.	N.	39 49	61	N.W.	·691	·698	·957
				S.	33 43·2	61		·706		
10.	−32 44	16 27	9 00 A.M.	N.	38 32·9	63	S.E.	·720	·724	·994
				S.	32 51·6	63		·728		
11.	−33 01	16 41	9 20 A.M.	N.	39 03·7	69	S.E. ½ E.	·708	·712	·976
				S.	33 21·2	69		·716		
12.	−33 13	16 46	3 45 P.M.	N.	38 23·4	69	S.S.E.	·724	·732	1·004
				S.	32 18·1	69		·740		
13.	−33 52	18 04	9 0 A.M.	N.	38 35·6	65	S. by W.	·719	·722	·991
				S.	33 00	65		·725		
14.	−34 16	17 34	9 30 A.M.	N.	38 31·8	61	E. by N.	·721	·712	·976
				S.	33 50·7			·703		

Minimum Intensity.—In the passage from England to the Cape of Good Hope the Expedition traversed three times that large space of the Atlantic in which the magnetic intensity is less than in any other part of the surface of the globe; first in a southerly course, in and about the meridian of 330° E.; a second time in beating up to St. Helena, in and about the meridian of 345° E.; and a third time in the course from St. Helena to the Cape of Good Hope, in and about the meridian of 350° E.

Before we examine more particularly the results of the observations made during these traverses, it will be proper to clear them from the effects of the ship's iron, as far as the data furnished will enable us to do so.

It is obvious, on a simple inspection of the results in the tables, that, in the southern hemisphere, when the ship's head was on the points from S. E. to S.W., the intensity observed was generally slightly in excess, and on the contrary, when on the points from N.E. to N.W., slightly in defect; and that such was the case in both ships. At St. Helena and at the Cape of Good Hope, an endeavour was made to ascertain more precisely the effect of the ship's iron in modifying the results, by placing the ship's head successively on the principal points of the compass, and observing the intensity in each position. At St. Helena, the experiment failed, owing, apparently, to the disturbing influence of the island itself, which, even at the distance at which the vessels were anchored, was found to be sufficient to mask the local attraction of the ship, and to produce anomalies which were not experienced at sea. At the Cape, the geological character of the land interposed no such difficulty. The following Table shows the differences found at Simon's Bay between the intensity observed on each of the sixteen principal points of the compass, and the arithmetical mean of the whole. Each difference has the sign prefixed which would be required for a correction to the arithmetical mean. Allowing for discrepancies incidental to single observations, the general aspect of the differences is sufficiently systematic to justify us in regarding them as principally occasioned by the influence of the ship's iron.

Ship's head.	Corrections.		Mean of the two ships.	Ship's head.	Corrections.		Mean of the two ships.
	Erebus.	Terror.			Erebus.	Terror.	
E.	+ ·002	+ ·001	+ ·001	W.	− ·000	+ ·010	+ ·005
E.S.E.	+ ·006	+ ·004	+ ·005	W.N.W.	000	+ ·009	+ ·004
S.E.	− ·002	− ·004	− ·003	N.W.	+ ·005	+ ·012	+ ·008
S.S.E.	+ ·001	− ·004	− ·002	N.N.W.	− ·004	+ ·008	+ ·002
S.	− ·007	− ·015	− ·011	N.	+ ·002	+ ·012	+ ·007
S.S.W.	− ·015	− ·015	− ·015	N.N.E.	+ ·003	+ ·012	+ ·007
S.W.	− ·012	− ·007	− ·010	N.E.	+ ·007	+ ·004	+ ·005
W.S.W.	+ ·005	− ·004	000	E.N.E.		+ ·001	+ ·001

This experiment was repeated at Kerguelen Island, but with the ship's head placed only on the eight principal points: the season and weather were unfavourable, and the errors of observation were consequently greater than at the Cape; but the general indication is the same: the results are as follows:

Ship's head.	Differences from the mean.		Mean of the two ships.	Ship's head.	Differences from the mean.		Mean of the two ships.
	Erebus.	Terror.			Erebus.	Terror.	
E.	+ ·008	— ·003	+ ·002	W.	+ ·006	+ ·007	+ ·006
S.E.	— ·007	000	— ·003	N.W.	000	+ ·008	+ ·004
S.	— ·016	— ·027	— ·021	N.	+ ·007	+ ·005	+ ·006
S.W.	— ·014	+ ·001	— ·006	N.E.	+ ·014	+ ·008	+ ·011

The experiments at the Cape and Kerguelen Island agree in indicating the points of greatest disturbance to be from S.E. (through south) to S.W., causing an augmentation,—and from N.E. (through north) to N.W., causing a diminution,—in the regular magnetic intensity; the augmentation on the southerly points being rather greater than the diminution on the northerly, compensated by there being a greater number of the remaining points in defect than in excess; the latter points being affected in a minor degree. Considering that the differences shown in the two last Tables necessarily combine the errors of observation with the influence of local attraction, we may regard the effect of the ship's iron on the intensity needle as probably amounting, in extreme cases, to $\frac{1}{100}$th of the earth's magnetic force; but on much the greater number of points as probably far less than that amount. In Table III., which contains the results of the almost daily observations made in the Erebus between December 7, 1839, and February 29, 1840, in the space of the Atlantic comprised between the two portions of the isodynamic curve of 0·9, I have employed the following scale of correction*:

Ship's head			Ship's head	
S.W. by S. to S.E. by S.	— ·008		W. and E.	+ ·001
S.W. and S.E.	— ·007		W. by N. and E. by N.	+ ·002
W.S.W. and E.S.E. . .	— ·002		W.N.W. and E.N.E. .	+ ·003
W. by S. and E. by S. .	000		N.W. and N.E. . .	+ ·004
			N.W. by N. to N.E. by N.	+ ·005

* After the communication of this paper to the Royal Society, I received from Captain Crozier the results of a third experiment of the same kind, made in the Terror on the 20th of October 1840 in the river Derwent in Van Diemen Island. I subjoin these results in further evidence of the general correctness of the deductions which have been drawn in regard to the influence of the ship's iron on the intensity observations made at sea.

Ship's head.	Correction.	Ship's head.	Correction.
E.	+ ·001	W.	+ ·003
E.S.E.	— ·001	W.N.W.	000
S.E.	— ·005	N.W.	+ ·007
S.S.E.	— ·008	N.N.W.	+ ·005
S.	— ·008	N.	+ ·004
S.S.W.	— ·007	N.N.E.	+ ·005
S.W.	— ·005	N.E.	+ ·008
W.S.W.	+ ·001	E.N.E.	+ ·002

Table III.

Abstract of the Intensities observed in Her Majesty's Ship Erebus, in the space of the Atlantic comprised within the isodynamic curve of 0·9.

Position. Lat. ° ′	Position. Long. E. ° ′	Intensity. °	Ship's head.	Correction for ship's head.	Corrected intensity. London = 1·372.
− 4 49	327 43	·921	S.S.W	−·008	·913
− 6 24	327 24	·897	S.	−·008	·889
− 7 50	327 28	·888	S.	−·008	·880
− 9 21	327 58	·870	S.S.E.	−·008	·862
−11 03	328 22	·856	S.S.E.	−·008	·848
−12 32	328 57	·840	S.E. by S.	−·008	·832
−14 0	329 28	·822	S.S.E.	−·008	·814
−15 04	330 06	·822	S.S.E.	−·008	·814
−16 52	330 27	·818	S. by E.	−·008	·810
−19 01	330 45	·814	S. ½ E.	−·008	·806
−21 31	330 47	·818	S.	−·008	·810
−21 47	330 50	·819	S.	−·008	·811
−23 14	330 55	·823	S. ½ W. / S.E.	−·008	·815
−24 22	331 51	·829	S.E. by S. / S.S.E.	−·008	·821
−25 40	332 46	·828	S.E. by E.	−·005	·823
−26 50	333 30	·839	S.S.E. / N. by E.	−·004	·835
−26 12	333 22	·833	S.E.	−·007	·826
−27 04	334 13	·836	S.E. by E.	−·005	·831
−27 43	335 06	·845	S. by E. / N.N.E. ½ E.	−·002	·843
−26 53	335 26	·840	N.N.E. / S.S.E.	−·002	·838
−26 01	335 20	·833	N. by E. / N.E. by N.	+·005	·838
−25 21	335 28	·826	S.E.	−·007	·819
−26 12	336 12	·829	S.E. by E.	−·005	·824
−27 04	337 25	·832	S.E.	−·007	·825
−27 43	338 37	·833	E.S.E.	−·002	·831
−28 19	340 10	·828	E. by S.	000	·828
−28 01	341 45	·828	E.N.E.	+·003	·831
−27 26	342 29	·830	N.E. by E.	+·003	·833
−26 47	342 57	·824	N.E. by N.	+·005	·829
−25 34	342 58	·823	N.N.E.	+·005	·828
−24 10	343 04	·812		+·005	·817
−22 40	343 42	·811	N.E. / N.E. ½ E.	+·004	·815
−21 30	344 17	·810	N.E. by E.	+·003	·813
−20 20	345 12	·810		+·003	·813
−18 53	345 46	·817		+·003	·820
−17 30	346 15	·820		+·003	·823
−17 11	346 40	·817		+·003	·820
−16 30	347 17	·816	N.E.	+·004	·820
−15 15	348 01	·821	N.E. by E. ½ E.	+·003	·824
−15 20	348 07	·813			
−15 49	348 09	·815	S.S.W. / E. by N. ½ N.	−·003	·812

Position. Lat. ° ′	Position. Long. E. ° ′	Intensity. °	Ship's head.	Correction for ship's head.	Corrected intensity. London = 1·372.
−15 30	348 51	·810	E.	+·001	·811
−14 33	349 37	·816	N.E. by E. / S.W. by S.	−·001	·815
−13 37	350 33	·822	S.S.W. / E. by N.	−·005	·817
−14 19	350 33	·813	E. ¼ N.	+·002	·815
−14 51	350 31	·815	E. W. / N. N.W.	+·003	·818
−14 08	351 31	·825	S.W. / N.E.	−·002	·823
−13 43	352 01	·823	S. by W. ½ W.	−·008	·815
−14 26	351 57	·825	S.	−·008	·817
−15 04	351 54	·825	S. by W.	−·008	·817
−15 23	352 06	·819		−·008	·811
−15 17	352 35	·820	S.	−·008	·812
−15 19	353 13	·820	E.N.E.	+·003	·823
−15 07	353 44	·829	S.S.W.	−·008	·821
−15 05	354 08	·825	S. by W.	−·008	·817
−17 26	353 28	·823	S.W.	−·007	·816
−18 53	352 45	·827	S.S.W.	−·008	·819
−20 51	351 55	·823		−·008	·815
−22 02	351 27	·821	S. by E.	−·008	·813
−22 21	351 22	·818	S. by W.	−·008	·810
−23 35	351 05	·821	W. / S.S.W.	−·002	·819
−23 47	350 29	·818	W. / E.	+·001	·819
−24 34	348 39	·818	W.	+·001	·819
−24 46	348 12	·820	W. / S.W.	−·001	·819
−25 19	347 54	·820	S.W.	−·007	·813
−25 31	347 45	·829		−·007	·822
−26 08	347 03	·826	W. E. / S. by E.	−·002	·824
−27 03	346 32	·844	S.S.W.	−·008	·836
−27 56	346 44	·834	S.E.	−·007	·827
−29 02	348 46	·836		−·007	·829
−30 14	351 37	·852		−·007	·845
−31 08	353 56	·849	S.E. ½ E.	−·006	·843
−31 46	356 38	·872	S.E. by E.	−·006	·866
−31 13	358 38	·872	E. by S.	000	·872
−30 20	359 50	·878	E. / S.E. / S.W.	−·005	·873
−31 13	359 39	·882	S.E. / S.W.	−·007	·875
−32 01	2 17	·886	S.E.	−·007	·879
−32 54	4 53	·914		−·007	·907

When these results are transferred to the map of the portion of the Atlantic to which they refer, and are examined in detail, their systematic character becomes much more obvious than in the Table, where, in consequence of the successive alternations of increasing and decreasing latitude, their consistency is not so easily followed by the eye. On attentive examination of the map it is not difficult to trace within small limits the course of an ideal line, which should connect the points in the several meridians, where the intensity was weakest at the epoch of Captain Ross's voyage. The determination of the position of this line is easier, and in some respects more sure, than that of an isodynamic line, because it is independent of the permanency of the magnetism of the needle employed, for more than the few days occupied in the immediate research; and it is also independent of the correctness of an assumed intensity at a base station. It is therefore to be expected that the position of this line will become in future years the subject of frequent examination, serving to mark, from time to time, the progress of the secular change in its position. This may be done with the more interest and advantage, because there is reason to believe that its position is changing rapidly in the space referred to, particularly in the eastern meridians; and that the southern magnetic hemisphere, in so far as its boundary may be indicated by this line, is in that quarter of the globe gaining rapidly upon the northern. In the first of the present series of "Contributions"*, the line of least intensity was drawn from observations corresponding nearly to the epoch of 1825, and this line of 1825 is lightly retraced in the present map for the purpose of comparison. It will be seen, that whilst its general direction is consistent with the observations of Captain Ross in 1840, its earlier position is everywhere three or four degrees south of that which would be now inferred. It is readily admitted that many of the observations from which the line of 1825 was drawn are inferior in precision to those of Captain Ross; and I rejoice in the late improvement in this class of observations, for which we are mainly indebted to the method and instrument devised by Mr. Fox, and to the zeal and unwearied patience of our naval officers. To an observer, however, who is proceeding in a nearly north and south direction, very little uncertainty attends the determination of the time and place at which he finds the weakest intensity; and if we compare the observations of Dunlop, Erman, and Sulivan, with those of Ross and Crozier, we invariably find that the earlier observer makes the place of the minimum a little more southerly than later determinations.

A glance at the map suffices to show where determinations are now most wanted, and to point out the track where additional observations would be most valuable: it would be nearly that of a vessel making the eastern passage to the Cape of Good Hope.

* Philosophical Transactions, 1840, Plate V.

§ 6. *Observations of Intensity between the Cape of Good Hope and Kerguelen Island.*

On the 6th of April 1840 the Expedition quitted Simon's Bay, and on the same night the Erebus and Terror parted company, and made their passage to Kerguelen Island on separate courses. Although the weather was very unfavourable, the practice of daily observation with the magnetical instruments was continued with very few exceptions, by the Erebus during the whole passage, and by the Terror from Simon's Bay as far as the meridian of the Crozet Islands, which was the first rendezvous. The observations of intensity on board the Erebus were chiefly made with deflector S, the other deflector N having been used only five times during the whole passage, whilst the number of observations with S amounts to thirty-six. For the values of w', in the case of deflector S, we have the comparisons with the constant weights at the Cape and Kerguelen Island, and three good intermediate comparisons at sea, viz. on the 11th, 12th, and 18th of April; a fourth attempt on the 1st of May failed from some accidental error in the observation with the constant weight. Pursuing the plan of graphical representation already described, we find that the line connecting the terminations of the ordinates at the Cape and at Kerguelen Island passes either through or extremely near the terminations of the other three ordinates, indicating the unchanged magnetism of the deflector; and we obtain the following Table of the values of w' for the degrees of deflection in the Table:

Values of w', deflector S, Erebus; Cape of Good Hope to Kerguelen Island.

°	grs.	°	grs.
25 =	2·628	31 =	2·426
26 =	2·594	32 =	2·392
27 =	2·560	33 =	2·358
28 =	2·527	34 =	2·324
29 =	2·494	35 =	2·291
30 =	2·460	36 =	2·260

Regarding the Cape as the primary station, and its intensity = 0·715 (London = 1), the intensity at the other stations is given by the formula

$$I' = \cdot 1837\ w' \operatorname{cosec} v'.$$

The observations with deflector N between the Cape and Kerguelen Island being few, and the two intermediate comparisons at sea with the constant weights exhibiting considerable discordances, either from the unfavourable circumstances of weather, or possibly in consequence of an actual small change of force in the deflector, I have not attempted to deduce results from the observations either with deflector N, or with N and S combined. I have also omitted in the mean deductions the results of the observations with the constant weight of one grain on the 1st of May and 29th of June, these observations being obviously affected with some accidental error.

For the Terror's deflectors we have only the comparisons with the constant weights at the Cape and Kerguelen Island from which to derive the values of w' for the intermediate degrees of v'. Connecting the values of w' obtained by those comparisons

for deflector N, with those in the former table for the same deflector, and presuming that the values corresponding to the intermediate degrees change in a nearly uniform progression, we derive the following Table for the degrees of v' observed between the Cape and Kerguelen Island:—

Values of w', deflector N, Terror; Cape of Good Hope to Kerguelen Island.	
° gr.	° gr.
26 = ·917	33 = ·873
27 = ·911	34 = ·866
28 = ·906	35 = ·859
29 = ·900	36 = ·852
30 = ·894	37 = ·845
31 = ·887	38 = ·837
32 = ·880	39 = ·828

The Cape being the primary station, and its intensity = 0·715, we obtain the intensities at the other stations by the formula

$$I' = \cdot 529\, w' \operatorname{cosec} v'.$$

In the case of deflector S, the values of w' which result from the comparisons with the constant weights at the Cape and Kerguelen Island are so nearly the same (·733 at the Cape, and ·735 at Kerguelen Island), that we may take the arithmetical mean ·734 for all the intermediate stations without sensible inconvenience; whence the formula for the calculation of the intensity becomes

$$I' = \cdot 388 \operatorname{cosec} v'.$$

As we have only the comparisons with the constant weights at the Cape and Kerguelen Island from which to derive the values of w' for the Terror's deflectors for all the intermediate degrees of v', we might be disposed to fear that the data were scarcely sufficient for that purpose; but when we examine the intensities deduced from the observations with the two deflectors (both having been used at all the intermediate stations except one), we perceive that their accordance is in general remarkably good, which would scarcely be the case unless the elements of calculation were tolerably correct. So close an agreement in the partial observations, in a passage made in tempestuous weather, is certainly very creditable both to the instrument and to the observers.

Those who interest themselves in examining the progress which magnetic maps of the portion of the globe occupied by sea are making towards accuracy, will compare the intensities between the Cape of Good Hope and Kerguelen Island, contained in the subjoined Tables, with the isodynamic lines drawn from Mr. Dunlop's observations in the first Number of these Contributions*. The prolongation of those lines into the more southerly latitudes traversed by the Erebus and Terror would suit extremely well with the intensities which are here given.

* Philosophical Transactions, 1840, Plate V.

Table IV.

Observations of the Magnetic Intensity on Shore and on Board Her Majesty's Ship Erebus, with Needle F 1, between the Cape of Good Hope and Kerguelen Island.

1840.	Position.		Time of day.	Method employed.	Deflection observed.	Thermometer.	Ship's head.	Intensity.		
	Lat.	Long. E.						London = 1·000.		= 1·372.
	° ′	° ′	h m		° ′	°				
April 3.	−34 11	18 26		S.	35 35	72	W.	·717		·984
7.	−35 14	18 27	11 40 A.M.	S.	35 23	71·5	S. by E.	·723		·992
8.	−35 48	18 47	10 A.M.	S.	35 11·1	70	E.S.E.	·728		·999
			10 45	S.	35 12	70	W. by S.	·728		
9.	−36 4	19 19	10 A.M.	S.	35 29·3	66·5		·720		·988
10.	−36 11	20 42	9 40 A.M.	S.	35 0·7	66·5	S.E. by S.	·733		1·005
11.			10 15 A.M.	S.	34 36·2	66·5		·745		
			10 40 A.M.	S. and N.	49 24·4	66·5				
			11 0 A.M.	N.	28 54·5	66·5			·742	1·018
			11 30 A.M.	weight 1 grain.	14 16·2	71		·744		
11.	−36 35	21 20	Noon.	weight 1½ grain.	22 10·2	71	S.	·731		
			0 30 P.M.	weight 2 grains.	29 40·0	71		·750		
12.	−37 19	21 37	10 30 A.M.	S.	33 48·8	72·5		·769		
			11 A.M.	S.	33 21	72·5		·784	·770	1·057
			11 40	weight 1 grain.	13 54·2	72·5		·763		
12.	−37 20	21 37	2 15 P.M.	S.	33 53·1	72		·766		
13.	−38 13	21 30	10 40 A.M.	S.	34 0·7		W.S.W.	·763		1·047
14.	−40 5	20 38		S.	34 25·5	62	S.S.E.	·750		1·029
15.	−40 29	22 22	11 30 A.M.	S.	33 5·5	68·5	S.E. by S.	·792		1·087
16.	−41 24	25 0	9 30 A.M.	S.	33 29·1	56	S.E. by S.	·780		1·071
			10 10 A.M.	S. and N.	47 59·5	56				
			10 50 A.M.	N.	27 32·5	56				
17.	−41 58	26 38	9 20 A.M.	S.	32 52·7	61·5	S.S.E.	·799		1·096
18.	−43 7	28 43	10 A.M.	S.	32 33·2	60	S.S.E.	·810		
			10 30 A.M.	S. and N.	47 9	60				
			10 40 A.M.	N.	26 48	60			·832	1·142
			11 0 A.M.	weight 1 grain.	12 44·3	59		·830		
			11 20 A.M.	weight 1½ grain.	18? 6·5*	59		·841		
			11 45 A.M.	weight 2 grains.	25 53·3	59		·849		
19.	−44 19	31 6	11 30 A.M.	S.	31 58·6	59	S.S.E.	·830		1·139
20.	−45 44	34 16	11 15 A.M.	S.	31 11	48·5		·859		1·179
21.	−47 00	37 14		S.	30 56·2	45	S.E. by E.	·868		1·191
22.	−47 00	38 48	6 30 A.M.	S.	31 15·6	44		·856		1·175
23.	−46 46	42 41	9 45 A.M.	S.	30 3·4			·902		1·237
24.	−47 1	46 10		S.	29 23	45	S.E. ½ E.	·929		1·275
26.	−46 41	50 52	11 20 A.M.	S.	29 10·7	44	S.E. by S.	·937		1·285
28.	−46 28	52 43	Noon.	S.	29 6·2	44	W.S.W.	·941		1·290
29.	−46 29	52 26	1 30 P.M.	S.	28 36·7	43	S.W. by W.	·962		1·319
30.	−46 18	52 4	11 30 A.M.	S.	28 20·5		S.S.W.	·974		1·336
May 1.	−46 25	52 1	10 30 A.M.	S.	28 25	45	S. by E. ½ E.	·970		1·331
			11 0 A.M.	S. and N.	42 36·2					
			11 30 A.M.	N.	21 49					
			Noon.	weight 1 grain.	11 13·3			·939†		
2.	−46 57	55 39	10 15 A.M.	S.	28 23	47	S.E.	·972		1·333
3.	−47 19	59 10	10 30 A.M.	S.	27 33·5	40		1·009		1·384
			10 50 A.M.	S. and N.	42 0·5					
			11 10 A.M.	N.	21 36					
4.	−47 41	62 59	9 40 A.M.	S.	26 22·5	43		1·068		1·466
7.	−48 36	69 21	Noon.	S.	26 7·5		N.N.W.	1·082		1·485
8.	−48 36	69 7		S.	25 54·7	39	S.W. by S.	1·091		1·497
11.	−48 30	69 52	9 30 A.M.	S.	25 49·5		S.W. by W. ½ W.	1·095		1·502
12.	−48 39	68 57	11 30 A.M.	S.	26 19·2		N.	1·070	1·085	1·488
			0 30 P.M.	S.	25 45·5		S.W. by W. ½ W.	1·100		

* 18° is probably an error of transcription, and should be 19°; the result of 18° 06′·5 would be ·885; that of 19° 06′·5 is ·841, as entered in the Table.

† Omitted in the mean.

Table IV. (Continued.)

1840.	Position. Lat.	Long. E.	Time of day.	Method employed.	Deflection observed.	Thermometer.	Ship's head.	Intensity. London = 1·000.		= 1·372.
			h		° ′	°				
May 18.	Christmas Harbour.		11 A.M.	S.	26 19·7	39	N.W.	1·069		1·467
June 26.	−48 41	68 54	Noon.	S.	26 21·3	34·5	Observed on shore.	1·068	1·068	1·465
			to	S. and N.	40 42·7					
			4 P.M.	N.	20 6·3					
29.			10 A.M. to	weight 1 grain.	10 24·1			1·010*		
			2 P.M.	weight $1\frac{1}{2}$ grain.	14 48·6			1·063		
				weight 2 grains.	20 19·6			1·073		
July 7.	Moored in Christmas Harbour.			S.	26 28·1		N.E.	1·062		
				S.	26 21·8		E.	1·068		
				S.	26 5·2		S.E.	1·083	1·076	
				S.	25 54·2		S.	1·092		
				S.	25 56·4		S.W.	1·090		
9.				S.	26 19·8	41	N.	1·069		
				S.	26 11·1		N.W.	1·076		
				S.	26 19·9		W.	1·070		

Table V.

Observations of the Magnetic Intensity on Shore and on Board Her Majesty's Ship Terror, with a four-inch Fox's Needle, between the Cape of Good Hope and Kerguelen Island.

1840.	Position. Lat.	Long. E.	Time of day.	Method employed.	Deflection observed.	Thermometer.	Ship's head.	Intensity. London = 1·000.		= 1·372.
			h m		° ′	°				
March 18.	Simon's Bay.		7 A.M.	N.	38 44·1		N.W.	·702	·712	·977
	−34 11	18 26		N.	38 35·8		W.N.W.	·705		
			8 A.M.	N.	38 39		W.	·704		
				N.	38 04·4		W.S.W.	·718		
			6 P.M.	N.	38 43·7		N.	·702		
				N.	38 32·6		N.N.W.	·706		
			6 30 P.M.	N.	38 46·3		N.N.E.	·702		
				N.	38 23·5		N.E.	·710		
19.			9 A.M.	N.	38 13·7		E.N.E.	·713		
				N.	38 22·9		E.	·710		
			9 30 A.M.	N.	38 26·0		E.S.E.	·709		
				N.	38 02·1		S.E.	·718		
			10 0 A.M.	N.	38 04·3		S.S.E.	·718		
				N.	37 40·8		S.	·729		
			11 0 A.M.	N.	37 43·2		S.S.W.	·728		
				N.	37 58·5		S.W.	·720		
21.			Noon.	N.	38 07·1		Observed on shore.	·715	·715	·981
23.			11 30 A.M.	N.	38 16·2					
21.				S.	32 59·3			·715		
23.				S.	32 43·8					
21.				weight ·5 grain.	21 46·1			·715		
23.				weight ·5 grain.	21 47·9					
21.				weight ·3 grain.	12 38·2			·715		
23.				weight ·3 grain.	12 56·5					

* Omitted in the mean.

Table V. (Continued.)

1840.	Position. Lat.	Position. Long. E.	Time of day.	Method employed.	Deflection observed.	Thermometer.	Ship's head.	Intensity. London = 1·000.		Intensity. = 1·372.
April 8.	−36° 16′	20° 04′	3 50 P.M.	N.	37° 31′·7	70°	S. by E.	·730	·731	1·003
				S.	32 00·2	70		·733		
10.	−36 52	18 25	9 20 A.M.	N.	37 53·1	66	W. ½ N.	·722	·724	·994
				S.	32 21·1	66		·726		
11.	−37 16	17 24	5 15 P.M.	N.	38 6	66	W.S.W.	·717	·722	·991
				S.	32 15·6	66		·728		
12.	−37 44	16 36	11 40 A.M.	N.	37 56·7	72	S.W.	·720	·721	·990
				S.	32 31·6			·722		
13.	−38 47	17 00	9 10 A.M.	N.	37 20·2	70	S.	·735	·734	1·007
				S.	31 59·9	70		·733		
14.	−38 58	17 26	9 05 A.M.	N.	36 47·8	62		·748	·750	1·028
				S.	31 07·4	62		·752		
15.	−40 45	19 20	3 50 P.M.	N.	36 49·4	68		·747	·760	1·044
				S.	30 09·7	68		·773		
16.	−42 40	22 02	3 45 P.M.	N.	35 37·7	56	S.E. by E.	·776	·775	1·063
				S.	30 11	56		·773		
17.	−42 56	23 12	9 30 A.M.	N.	35 21·7	61	S.	·782	·788	1·081
				S.	29 15·3	61		·795		
18.	−44 28	24 55	9 20 A.M.	N.	34 28·5	60		·807	·805	1·104
				S.	28 56·4	60		·803		
19.	−46 0	26 12	1 P.M.	N.	33 48·0	59	S.S.E.	·828		1·136
20.	−46 41	29 0	9 20 A.M.	N.	33 56·0	48	S.E. by E.	·821	·822	1·127
				S.	28 13·1	48		·822		
23.	−46 45	40 05	9 40 A.M.	N.	32 12·1	44	S.E. ½ E.	·873	·866	1·189
				S.	26 52·8	44		·859		
24.	−47 0	43 48	9 30 A.M.	N.	31 28·7	45		·896	·901	1·236
				S.	25 24·7	45		·905		
25.	−47 50	45 20	2 40 P.M.	N.	30 37·7	44		·924	·924	1·268
				S.	24 52·1	44		·924		
July 3.	Christmas Harbour, Kerguelen Island.		10 A.M.	N.	27 03·1	36	Observed on shore.	1·0675	1·0675	1·465
4.			2 P.M.	N.	26 41	36				
3.			A.M.	S.	21 31·3	36		1·0675		
4.			P.M.	S.	21 14·0	36				
3.	−48 41	68 54	A.M.	weight ·5 grain.	14 18·5	36		1·070		
4.			P.M.	weight ·5 grain.	14 13·7	36				
3.			A.M.	weight ·3 grain.	8 29·7	36		1·065		
4.			P.M.	weight ·3 grain.	8 29·5	36				
7.	−48 41	68 54	Noon.	N.	26 37·1	38	N.	1·079	1·084	
				N.	26 41·4	38	N.E.	1·076		
			1 0 P.M.	N.	26 26·2	38	E.	1·087		
				N.	26 29·8	38	S.E.	1·084		
			1 30 P.M.	N.	25 54·7	38	S.	1·111		
				N.	26 32·1	38	S.W.	1·083		
			2 0 P.M.	N.	26 40·3	38	W.	1·077		
				N.	26 40·8	38	N.W.	1·076		

Table VI.

Abstract of the Intensities observed in Her Majesty's Ships Erebus and Terror between the Cape of Good Hope and Kerguelen Island.

Position. Lat.	Position. Long. E.	In which ship observed.	Intensity.	Ship's head when at sea.	Correction for ship's head.	Corrected intensity. London = 1·372.
−34° 11′	18° 26′	Erebus and Terror.	0·981	Observed on shore.		0·981
−37 44	16 36	Terror.	0·990	S.W.	−·007	0·983
−35 14	18 27	Erebus.	0·992	S. by E.	−·008	0·984
−36 04	19 19	Erebus.	0·988	W. by S.	·000	0·988
−37 16	17 24	Terror.	0·991	W.S.W.	−·002	0·989
−36 16	20 04	Terror.	1·003	S. by E.	−·008	0·995
−36 52	18 25	Terror.	0·994	W. ½ N.	+·002	0·996
−36 11	20 42	Erebus.	1·005	S.E. by S.	−·008	0·997
−35 48	18 47	Erebus.	0·999	E.S.E. W. by S.	−·001	0·998
−38 47	17 00	Terror.	1·007		−·008	0·999
−36 35	21 20	Erebus.	1·018	S.	−·008	1·010
−38 58	17 26	Terror.	1·028		−·008	1·020
−40 05	20 38	Erebus.	1·029	S.S.E.	−·008	1·021
−40 45	19 20	Terror.	1·044	S.	−·008	1·036
−38 13	21 30	Erebus.	1·047	W.S.W.	−·002	1·045
−42 40	22 02	Terror.	1·063	S.E. by E.	−·005	1·058
−41 24	25 0	Erebus.	1·071	S.E. by S.	−·008	1·063
−42 56	23 12	Terror.	1·081	S.	−·008	1·073
−40 29	22 22	Erebus.	1·087	S.E. by S.	−·008	1·079
−41 58	26 38	Erebus.	1·096	S.S.E.	−·008	1·088
−44 28	24 55	Terror.	1·104	S.	−·008	1·096
−46 41	29 0	Terror.	1·127	S.E. by E.	−·005	1·122
−46 0	26 12	Terror.	1·136		−·008	1·128
−44 19	31 06	Erebus.	1·139	S.S.E.	−·008	1·131
−43 07	28 43	Erebus.	1·142		−·008	1·134
−47 00	38 48	Erebus.	1·175	S.E. by E.	−·005	1·170
−45 44	34 16	Erebus.	1·179	S.S.E.	−·008	1·171
−46 45	40 05	Terror.	1·189	S.E. ½ E.	−·006	1·183
−47 00	37 14	Erebus.	1·191	S.E. by E.	−·005	1·186
−47 0	43 48	Terror.	1·236	S.E. ½ E.	−·006	1·230
−46 46	42 41	Erebus.	1·237	S.E. by E.	−·005	1·232
−47 50	45 20	Terror.	1·268	S.E. ½ S.	−·007	1·261
−47 01	46 10	Erebus.	1·275	S.E. ½ E.	−·006	1·269
−46 41	50 52	Erebus.	1·285	S.E. by S.	−·008	1·277
−46 28	52 43	Erebus.	1·290	W.S.W.	−·002	1·288
−46 29	52 26	Erebus.	1·319	S.W. by W.	−·005	1·314
−46 25	52 01	Erebus.	1·331	S. by E. ½ E.	−·008	1·323
−46 57	55 39	Erebus.	1·333	S.E.	−·007	1·326
−46 18	52 04	Erebus.	1·336	S.S.W.	−·008	1·328
−47 19	59 10	Erebus.	1·384	S.E.	−·007	1·377
−47 41	62 59	Erebus.	1·466		−·007	1·459
−48 41	68 54	Erebus and Terror.	1·465	Observed on shore.		1·465
−48 41	68 54	Erebus.	1·467	N.W.	+·004	1·471
−48 39	68 57	Erebus.	1·488	N. S.W. by W. ½ W.	000	1·488
−48 36	69 07	Erebus.	1·497	S.W. by S.	−·008	1·489
−48 36	69 21	Erebus.	1·485	N.N.W.	+·005	1·490
−48 30	69 52	Erebus.	1·502	S.W. by W. ½ W.	−·005	1·497

III. *Researches in Physical Geology.—Third Series.* *By* W. Hopkins, *Esq., M.A., F.R.S., Fellow of the Royal Astronomical Society, of the Geological Society, and of the Cambridge Philosophical Society.*

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On the Thickness and Constitution of the Earth's Crust.

1. THE result at which I arrived in my preceding memoir, respecting the precessional motion of the pole, on the hypothesis of the earth's interior fluidity, is the following:

$$P' - P_1 = \left(1 - \frac{\varepsilon}{\varepsilon_1}\right)\left(1 - \frac{\eta}{1 + \frac{h}{q^5 - 1}}\right) P_1, \quad \ldots \ldots \ldots \quad (1.)$$

where P_1 denotes the precession of a solid homogeneous spheroid of which the ellipticity $= \varepsilon_1$, that of the earth's exterior surface, and P' the precession of the earth, supposing it to consist of an interior heterogeneous fluid, contained in a heterogeneous spheroidal shell, of which the interior and exterior ellipticities are respectively ε and ε_1, the transition being immediate from the entire solidity of the shell to the perfect fluidity of the interior mass.

2. In the application of this result to the actual case of the earth, we must observe, in the first place, that, supposing the interior mass to be fluid, its fluidity cannot be quite *perfect*, as explained in the introductory observations to my first memoir. Consequently the assumption, made in our investigations, of the absence of all tangential action between the shell and fluid will not be accurately true. Moreover, it would seem extremely probable that the transition from the solidity of the shell to the fluidity of the interior mass, instead of being immediate, must be gradual. If, however, the thickness of the shell be not considerable with reference to the earth's radius, the fluidity of the portion not remote from the centre will be nearly perfect, and the whole of the interior mass, with the exception of that part near the actual solid portion, may, as a near approximation, be considered as perfectly fluid with reference to any mechanical action upon it. Again, supposing the change from the solidity of the exterior to the fluidity of the interior mass to be continuous, let us conceive a surface passing through all the lowest points of that portion of the mass which may be regarded as perfectly solid, and another surface through all the highest points of that portion which may be regarded as perfectly fluid. The first of these surfaces will be one of equal solidity and the second one of equal fluidity; the fluidity of the mass contained between them being imperfect. Now if we were to consider

the whole of this imperfectly fluid mass as entirely solid, we should manifestly take the thickness of the shell too large to represent the actual phenomena depending on that thickness; and if, on the contrary, we should consider the whole of the imperfectly fluid portion as perfectly fluid, we should take the thickness of the shell too small. Hence there must be some surface of equal fluidity (or, if we please so to term it, of equal *solidity*) intermediate to the above surfaces, such that if the whole mass superior to it were entirely solid, and that inferior to it entirely fluid, the phenomena of precession and nutation would be the same as in the actual case of a gradual transition from the solidity of the superior to the fluidity of the inferior portions of the mass. When, therefore, we speak of the interior surface of the solid shell with reference to our previous investigations as applicable to the case of the earth, it is this intermediate, or *effective surface*, which is always to be understood; and the thickness of the earth's crust, as defined by this surface, I shall term its *effective thickness*.

3. In order that the value of P' may agree with that determined by observation, we must have approximately

$$P' - P_1 = \frac{1}{8} P_1,$$

and, therefore, referring to the equation of Article 1, we must have

$$\left(1 - \frac{\varepsilon}{\varepsilon_1}\right)\left(1 - \frac{\eta}{1 + \frac{h}{q^5 - 1}}\right) = \frac{1}{8}. \quad \ldots \ldots \ldots \quad (2.)$$

An approximate value of $\frac{h}{q^5 - 1}$ will be obtained by making ϱ constant in the expression given for it in Article 5, Mem. II. We then have

$$\frac{h}{q^5 - 1} = \frac{2\,a^5}{a_1^{\,5} - a^5},$$

$$= \frac{2}{q^5 - 1}, \qquad \left(q^5 = \frac{a_1}{a}\right);$$

which gives

$$\left(1 - \frac{\varepsilon}{\varepsilon_1}\right)\left(1 - \eta \, . \, \frac{q^5 - 1}{q^5 + 1}\right) = \frac{1}{8}.$$

It has been stated (Art. 2. Mem. II.), that if η be ever negative, it can only be so when $a = a_1$ very nearly. But in this case $q^5 - 1$ is extremely small, and therefore the value of the second factor on the left-hand side of the above equation will be very nearly = unity. In all other cases it will be less than unity. Let it $= 1 - \beta$; then

$$1 - \frac{\varepsilon}{\varepsilon_1} = \frac{1}{8} \cdot \frac{1}{1 - \beta},$$

and

$$\frac{\varepsilon}{\varepsilon_1} = 1 - \frac{1}{8} \cdot \frac{1}{1 - \beta}.$$

If, as an approximation, we omit β (which will necessarily be considerably smaller

than unity for such values of $\frac{a_1}{a}$ as we shall be concerned with), we have

$$\frac{\varepsilon}{\varepsilon_1} = 1 - \frac{1}{8} = \frac{7}{8}, \quad \ldots \ldots \ldots \ldots \quad (3.)$$

which gives *too great* a value of ε. Now, that we may be able to satisfy equation (2.), ε must be less than ε_1, *i. e.* it must diminish as the thickness of the earth's crust increases; and, therefore, the thickness which corresponds to this approximate value of ε will be *too small*; or the actual thickness of the solid crust of the globe which would give the precession P′, must necessarily be *greater* than that for which the value of ε is $\frac{7}{8}\varepsilon_1$.

4. We must now proceed to determine the relation between the value of $\frac{\varepsilon}{\varepsilon_1}$ and that of $a_1 - a$, the thickness of the solid crust.

If we assume (as I shall now do) that the fusibility of the matter composing the earth is equal at equal depths*, it would seem that the only conceivable causes which can affect the degree of solidity or fluidity of the mass, are *temperature* and *pressure*. It may be doubted by some persons whether solidification be actually promoted by the latter cause or not; but there will be no corresponding uncertainty in our conclusions respecting the minimum thickness of the earth's crust consistent with the observed amount of precession; because, if they be true, this cause being effective, they will easily be seen to be so, *à fortiori*, if it produce no effect.

If temperature produced no effect in solidification, the surfaces of equal solidity (or fluidity) would be surfaces of equal pressure, and therefore of equal density; and if pressure did not promote solidification, the surfaces of equal solidity would be isothermal surfaces. Assuming both causes to be effective, conceive two surfaces of equal density and temperature respectively, passing through the same point (in the axis of the spheroid, for instance); then will the surface of equal solidity through the same point be intermediate to the two former, the ellipticities of which will therefore be *limits* to that of the surface of equal solidity. It is these limits which we must now proceed to determine.

The greatest difficulty in the determination of the temperature at any point of a body cooling by conduction, is that which arises from satisfying the conditions at the surface in each particular case. This has been effected only in the sphere, the circular cylinder, and a few other simple cases, but not including that of the spheroid, the *isothermal surfaces* of which, consequently, have never been completely determined†.

* This may admit of local exceptions, such as probably exist, without any sensible modifications in our general conclusions.

† An ingenious memoir on this subject by M. Lamé is contained in the fifth volume of the 'Mémoires des Savans Etrangers,' in which he has examined the conditions under which the isothermal surfaces within an ellipsoid will also be ellipsoids, when it has arrived at a permanent state of temperature. He has also made the general expression for the temperature at any time to depend on the integration of certain differential equa-

The approximate solution which I am about to offer is founded on the following assumption. Let r' be the distance of any point on the surface of the spheroid from the centre, and a_1 the polar or least distance; it is assumed that the temperature in the spheroid at a depth $= r' - a_1$ is the same as it would have been at that depth if the spheroid had been a sphere with radius $= r'$. If the ellipticity be small, and the process of cooling has been continued a sufficient length of time, this assumption will manifestly be almost accurately true. The solution of the problem is thus made to depend on formulæ which have been given by POISSON in his *Théorie de la Chaleur*. To this I now proceed.

§. *Determination of the Forms of Isothermal Surfaces within the Earth.*

5. Adopting POISSON's notation*, let u denote, at any time t, the temperature of any point of the earth, and let

$$u = u_1 + u',$$

where u_1 is such as to satisfy the general differential equation for the propagation of heat by conduction, the conditions relative to the original temperature, and that which would exist at the surface at any time if the earth were a sphere whose radius $= a_1$. Then when t becomes very great, as it is assumed to be in the case of the earth, taking the common expression for the temperature in a sphere of large radius, as a sufficient approximation to that of the actual case of the earth, we have

$$u_1 = \mathrm{C}\frac{a_1}{\pi r}\left(\sin\frac{r}{a_1}\pi - \frac{\pi r}{b\,a_1^2}\cos\frac{\pi r}{a_1}\right)\varepsilon^{-\frac{\alpha^2\pi^2}{a_1^2}t},$$

where C is the value of u_1 at the centre†. At the surface the first term vanishes, and the value of u_1 is reduced to the second term, which, however, is so small that it may here be altogether neglected. Consequently

$$u_1 = \mathrm{C}\frac{a_1}{\pi r}\sin\frac{r}{a_1}\pi\,\varepsilon^{-\frac{\alpha^2\pi^2}{a_1^2}t}.$$

Let ζ denote the value of u at any point for which $r = a_1$, ζ being a function of t and of θ, the angle which r makes with the axis of revolution of the spheroid; or since (t being very large) $u_1 = 0$, approximately when $r = a_1$, ζ may be taken as the value of u' for that value of r. It remains to find a value of u' which shall satisfy the general differential equation, and the particular condition $u' = \zeta$ when $r = a_1$‡.

Let

$$r\,u' = \mathrm{U}_0 + \mathrm{U}_1 + \dots + \mathrm{U}_n + \dots,$$

$\mathrm{U}_0 \dots \mathrm{U}_n \dots$ being a series of LAPLACE's coefficients, and functions of the polar coordinates of the proposed point. Also let

$$\zeta = (\mathrm{Z}_0 + \mathrm{Z}_1 + \dots + \mathrm{Z}_n + \dots)\,\varepsilon^{-mt},$$

tions of one independent variable, and of the second order. The complicated form of these equations, however, would seem to render them at present of little avail in the solution of the problem considered in the text.

* Théorie de la Chaleur, Art. 173. † Ibid. Art. 171. ‡ Ibid. Art. 173.

a series likewise of LAPLACE's coefficients, independent of r. Then shall we have*

$$U_n = R_n Z_n \varepsilon^{-mt},$$

where $R_n = M_n r^{n+1} \int_0^{\pi} \cos\left(\frac{r\sqrt{m}}{a} \cos\omega\right) \sin^{2n+1}\omega \,.\, d\omega$, M_n being an arbitrary constant. Hence if we denote the value of the definite integral by N_n, we shall have

$$u' = \left\{M_0 N_0 Z_0 + \ldots . + M_n N_n r^n Z_n + \ldots .\right\} \varepsilon^{-mt}.$$

When $r = a_1$, u' must $= \zeta$; and therefore if the corresponding value of N_n be denoted by (N_n), we shall have

$$M_0 (N_0) Z_0 + \ldots . + M_n (N_n) a^n_1 Z_n + \ldots . = Z_0 + \ldots . + Z_n + \ldots .,$$

which gives for the determination of M_n,

$$M_n = \frac{1}{a_1^n (N_n)};$$

whence

$$u' = \left\{\frac{N_0}{(N_0)} Z_0 + \ldots . + \frac{N_n}{(N_n)} \cdot \frac{r^n}{a_1^n} Z_n + \ldots .\right\} \varepsilon^{-mt}.$$

According to our assumptions for the value of ζ (Art. 4.), we must have ζ equal to the temperature (u_1) in a sphere, whose radius $= r'$, at a distance $r' - a_1$ from its surface. Therefore†

$$\zeta = C \,.\, \frac{1}{b r'} \left\{1 + b(r' - a_1)\right\} \varepsilon^{-\frac{\alpha^2 \pi^2}{r'^2} t};$$

or omitting $\frac{1}{b r'}$,

$$\zeta = C \frac{r' - a_1}{r'} \varepsilon^{-\frac{\alpha^2 \pi^2}{r'^2} t},$$

C being the temperature at the centre. Or since

$$r' = a_1 (1 + \varepsilon_1 \cos^2\theta),$$

$$\zeta = C \varepsilon_1 \cos^2\theta \, \varepsilon^{-\frac{\alpha^2 \pi^2}{a_1^2} t},$$

omitting smaller terms.

It is here supposed that the temperature of the surface of the earth is constant and equal to zero. If we take into account the variation of external temperature in passing from the pole to the equator, we have only to consider ε_1 as the ellipticity of that surface of equal temperature which touches the earth's surface at the equator, the temperature there being also assumed as zero. Then ε_1 will be rather greater than the ellipticity of the earth.

Putting the expression for ζ under the form of LAPLACE's coefficients, we have

$$\zeta = C \varepsilon_1 \left\{\frac{1}{3} + \left(\cos^2\theta - \frac{1}{3}\right)\right\} \varepsilon^{-\frac{\alpha^2 \pi^2}{a_1^2} t},$$

$$= \left\{\frac{C \varepsilon_1}{3} + C \varepsilon_1 \left(\cos^2\theta - \frac{1}{3}\right)\right\} \varepsilon^{-\frac{\alpha^2 \pi^2}{a_1^2} t},$$

* Théorie de la Chaleur, Art. 173.

† Ibid. Art. 171.

which gives $Z_n = 0$, except for $n = 0$, or $n = 2$; and

$$Z_0 = \frac{C\,\varepsilon_1}{3}, \quad Z_2 = C\,\varepsilon_1\left(\cos^2\theta - \frac{1}{3}\right);$$

also

$$m = \frac{\alpha^2\,\pi^2}{a_1^{\,2}}.$$

Hence

$$u^1 = C\,\varepsilon_1\left\{\frac{1}{3}\left(\frac{N_0}{(N_0)} - \frac{N_2}{(N_2)}\cdot\frac{r^2}{a_1^{\,2}}\right) + \frac{N_2}{(N_2)}\cdot\frac{r^2}{a_1^{\,2}}\cos^2\theta\right\}\varepsilon^{-\frac{\alpha^2\,\pi^2}{a_1^{\,2}}t}.$$

It remains to determine N_0, (N_0), N_2, and (N_2). We have

$$N_n = \int_0^{\pi}\cos\left(\frac{r}{a_1}\pi\cos\omega\right)\sin^{2n+1}\omega\,d\omega;$$

or putting $\cos\omega = x$,

$$N_n = \int_{-1}^{+1}\cos\left(\frac{r}{a_1}\pi\,.\,x\right)(1 - x^2)^n\,dx;$$

and performing the integrations for $n = 0$ and $n = 2$, we obtain

$$N_0 = \frac{2}{\pi}\cdot\frac{a_1}{r}\sin\frac{r}{a_1}\pi,$$

$$N_2 = \left(\frac{48}{\pi^5}\cdot\frac{a_1^{\,5}}{r^5} - \frac{16}{\pi^3}\cdot\frac{a_1^{\,3}}{r^3}\right)\sin\frac{r}{a_1}\pi - \frac{48}{\pi^4}\cdot\frac{a_1^{\,4}}{r^4}\cos\frac{r}{a_1}\pi;$$

and putting $r = a_1$, we have

$$(N_0) = 2,$$

$$(N_2) = \frac{48}{\pi^4}.$$

Hence

$$\frac{N_0}{(N_0)} = \frac{1}{\pi}\cdot\frac{a_1}{r}\sin\frac{r}{a_1}\pi,$$

$$\frac{N_2}{(N_2)} = \left(\frac{1}{\pi}\cdot\frac{a_1^{\,5}}{r^5} - \frac{\pi}{3}\cdot\frac{a_1^{\,3}}{r^3}\right)\sin\frac{r}{a_1}\pi - \frac{a_1^{\,4}}{r^4}\cos\frac{r}{a_1}\pi;$$

and by substitution, we have the complete value of u'; and for that of u we have

$$u = C\left\{\frac{a_1}{\pi r}\sin\frac{r}{a_1}\pi + \frac{\varepsilon_1}{3}\left(\frac{N_0}{(N_0)} - \frac{N_2}{(N_2)}\frac{r^2}{a_1^{\,2}}\right) + \varepsilon_1\frac{N_2}{(N_2)}\frac{r^2}{a_1^{\,2}}\cos^2\theta\right\}\varepsilon^{-\frac{\alpha^2\,\pi^2}{a_1^{\,2}}t};$$

or putting

$$\frac{u\,\varepsilon^{\frac{\alpha^2\,\pi^2}{a_1^{\,2}}t}}{C} = G,$$

we have for the equation to the isothermal surface, of which the temperature is u at the time t,

$$G = \frac{a_1}{\pi r}\sin\frac{r}{a}\pi + \frac{\varepsilon_1}{3}\left(\frac{N_0}{(N_0)} - \frac{N_2}{(N_2)}\frac{r^2}{a_1^{\,2}}\right) + \varepsilon_1\frac{N_2}{(N_2)}\frac{r^2}{a_1^{\,2}}\cos^2\theta.$$

Suppose

$$r = a_1 - x,$$
$$= a_1\left(1 - \frac{x}{a_1}\right),$$

where $\frac{x}{a_1}$ is small compared with unity. Then we have approximately

$$\frac{a_1}{\pi r}\sin\frac{r}{a_1}\pi = \frac{x}{a_1}\left(1 + \frac{x}{a_1}\right),$$
$$\frac{N_0}{(N_0)} = \frac{x}{a_1}\left(1 + \frac{x}{a_1}\right),$$
$$\frac{N_2}{(N_2)}\cdot\frac{r^2}{a_1^2} = 1 - \frac{\pi^2 - 9}{3}\cdot\frac{x}{a_1};$$

and therefore

$$G = \left(1 + \frac{\varepsilon_1}{3}\right)\frac{x}{a_1}\left(1 + \frac{x}{a_1}\right) - \frac{\varepsilon_1}{3}\left(1 - \frac{\pi^2 - 9}{3}\cdot\frac{x}{a_1}\right) + \varepsilon_1\left(1 - \frac{\pi^2 - 9}{3}\cdot\frac{x}{a_1}\right)\cos^2\theta.$$

We may here omit $\left(\frac{x}{a_1}\right)^2$ and the products of $\frac{x}{a_1}$ and ε_1, except in the last term, in which we may substitute for $\frac{x}{a_1}$ its approximate value, G. We have thus (putting $a_1 - r$ for x),

$$G = 1 - \frac{r}{a_1} + \left(1 - \frac{\pi^2 - 9}{3}G\right)\varepsilon_1\cos^2\theta;$$

whence

$$\frac{r}{a_1} = (1 - G)\left\{1 + \frac{1 - \frac{\pi^2 - 9}{3}G\,\varepsilon_1\cos^2\theta}{1 - G}\right\};$$

and

$$r = (1 - G)\,a_1\left[1 + \left\{1 + \left(1 - \frac{\pi^2 - 9}{3}\right)G\right\}\varepsilon_1\cos^2\theta\right],$$

the aproximate equation to the isothermal surface.

Hence it appears that the ellipticities of the isothermal surfaces within the earth are *greater* than that of the surface. Thus if $G = \frac{x}{a_1} = \frac{1}{10}$, we have

$$\text{ellipticity} = (1 + \cdot 07)\,\varepsilon_1 \text{ nearly}.$$

It will also be observed that it increases with G, i. e. with the depth. A further approximation gives a somewhat slower rate of increase, but the inference from the above formula is sufficient for our purpose.

§. *Ellipticity of any Surface of equal density within the Earth.*

6. If we assume the density of the earth (ϱ) at any distance (a) from its centre to be such that

$$\varrho = A\frac{\sin q' a}{a},$$

(A being constant), and take $q' a = 150°$, we obtain a value of ε_1 (the ellipticity of the surface) which coincides very nearly with its observed value, as shown in the common treatises on the figure of the earth. This expression for ϱ also gives us the ratio of the mean to the superficial density equal to 2·4225*, which agrees very nearly with the value determined by CAVENDISH. It therefore appears extremely probable that this formula represents very approximately the actual law of the earth's density.

The above expression for ϱ gives us

$$\frac{\varepsilon}{\varepsilon_1} = \frac{\tan q' a_1 - q' a_1}{\tan q' a - q' a} \cdot \frac{\left(1 - \frac{3}{q'^2 a^2}\right) \tan q' a + \frac{3}{q' a}}{\left(1 - \frac{3}{q'^2 a_1^2}\right) \tan q' a_1 + \frac{3}{q' a_1}}.$$

If we here substitute the above value of $q' a_1$, and put $a = \frac{3}{4} a_1$, we obtain a value of ε which nearly satisfies equation (3.) (Art. 1.).

If we take $q' a_1 = 160°$ we obtain the mean density more than three times the superficial density, and a value of ε_1 not so nearly coinciding with the observed value as in the former case. In this case the formula probably gives us a density increasing too rapidly with the depth, and therefore also a too rapid decrease of ellipticity in the surfaces of equal density. To obtain a value of ε, which will satisfy equation (3.), we must put a equal to about $\frac{4}{5} a_1$.

§. *Thickness of the Earth's Crust.*

7. If the surfaces of equal solidity were coincident with those of equal density, and we adopted the first value of $q' a_1$ mentioned in the preceding article, we should obtain the *effective thickness* of the crust $(= a_1 - a) = \frac{a_1}{4} = 1000$ miles; or if we adopt the other value of $q' a_1$ as less favourable to a great thickness of the crust, we shall have that thickness = 800 miles. But the surface of equal solidity through any point must be intermediate between those of equal density or pressure, and of equal temperature through the same point; and we have seen (Art. 5.) that the ellipticity of the latter increases with the distance from the external surface. Consequently the ellipticity of every surface of equal solidity must be greater than that of the corresponding surface of equal density, and, therefore, the effective thickness of the crust must be greater than that above determined, in order that it may be consistent with the observed amount of precession.

The thickness of the actually solid portion of the earth's crust will necessarily be less than what I have termed the effective thickness, but there cannot, I conceive, be any reasonable doubt that the difference between these quantities is small compared with either; for if τ_1 be the highest temperature at which any substance retains the property of solidity, and τ_2 the lowest at which it acquires that of fluidity, $\tau_2 - \tau_1$ is

* AIRY'S Tracts, p. 178.

always found to be small compared with τ_1; and by analogy we conclude that such must be the case also with respect to the matter composing the earth, and under the pressure to which it is subjected at great depths. We may also remark, that the position of a surface of equal solidity or fluidity must necessarily so far incline to the corresponding surface of equal temperature as to differ materially from that of equal density, so that the real effective thickness of the crust is probably considerably greater than its inferior limit as above determined. Upon the whole, therefore, we may venture to assert that the minimum thickness of the crust of the globe which can be deemed consistent with the observed amount of precession, cannot be less than one-fourth or one-fifth of the earth's radius.

§. *Constitution of the Earth's Crust.*

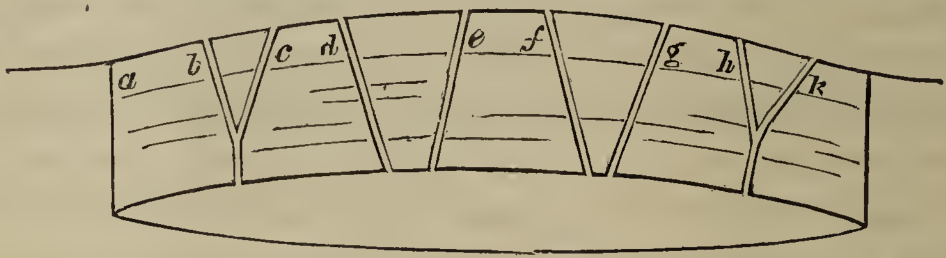
8. The results at which we have arrived respecting the thickness of the solid crust of the globe, have an important bearing on our physical theories of volcanic forces, and the mode in which they act, whether we consider the subject with reference to existing volcanos, or to that more general volcanic action to which we refer all the geological phenomena of elevation. Many speculations respecting actual volcanos have rested on the hypothesis of a direct communication, by means of the volcanic vent, between the surface and the fluid nucleus beneath, assuming the fluidity to commence at a depth little, if at all, greater than that at which the temperature may be fairly presumed to be such as would suffice, under merely the atmospheric pressure, to fuse the matter of the earth's crust*. When it is proved, however, that that crust must be several hundred miles in thickness, the hypothesis of this direct communication is placed, as I conceive, much too far beyond the bounds of all rational probability to be for an instant admitted as the basis of theoretical speculations. We are necessarily led, therefore, to the conclusion that the fluid matter of actual volcanos exists in subterranean reservoirs of limited extent, forming subterranean *lakes*, and not a subterranean *ocean*. Such also we conclude from the present thickness of the earth's crust, must have been the case for enormous periods of time; and, consequently, that there is a very high degree of probability that the same was true at the epochs of all the great elevations which we recognize, with the exception, perhaps, of the earliest. If, moreover, we find that the hypothesis of the existence of these subterranean lakes at no great depth beneath the surface, does enable us to account distinctly, by accurate investigations founded on mechanical principles, for the phenomena of elevation and the laws which they follow, then have we all the proof of the truth of our hypothesis which the nature of the case will admit of. These investigations I have given in my memoir on Physical Geology, published in the sixth volume of the Transactions of the Cambridge Philosophical Society. The fundamental

* Some of the most ingenious and determinate speculations of this kind are contained in a paper by Professor Bischoff, in the Edinburgh New Philosophical Journal for 1838–39. His views respecting the immediate agency by which volcanic action is produced will be equally applicable, whether the reservoir of volcanic matter beneath be of limited extent, or the central nucleus itself.

hypothesis of these investigations is thus found to be in perfect harmony with the results of the remoter researches contained in this and my two preceding memoirs.

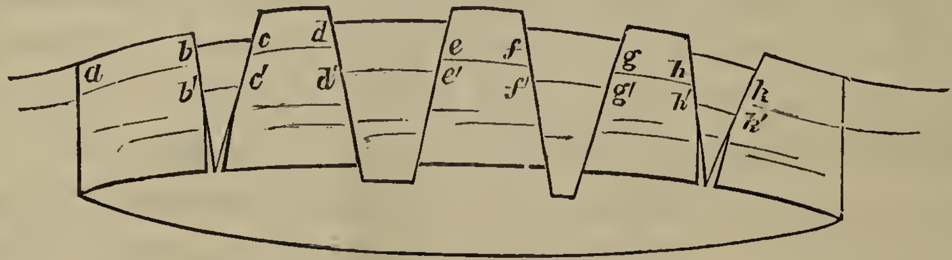
9. A question here arises as to the origin and continued existence of these insulated fluid masses enveloped in the solid portions of the earth. It would seem probable, I think, that their origin may be ascribed to the greater fusibility of the matter composing them; and their continuance in a state of fluidity may, I conceive, be accounted for partly by the same cause, and partly by another which I will proceed to explain.

Let us conceive an internal lake to have been formed as above supposed, or in any other manner, at a temperature which would just admit of the containing rock becoming solid, while it sufficed to preserve the fluid mass in a state of fusion. Let us then suppose an elevatory force, produced by the expansion of the fluid matter*, to raise the superincumbent solid mass, and to form in it a system of fissures. The plane of these fissures will scarcely ever be exactly parallel, and therefore will meet if sufficiently produced. Let the annexed diagram represent a transverse section of



(1.)

the system the instant after their formation, and before any relative displacement by further elevation, of the portions of the general mass contained between contiguous fissures, and forming so many complete or truncated wedges. The formation of these fissures will be completed at nearly the same instant of time†. Conceive the mass to be then still further uplifted. If every portion were raised equally, the width of the fissures would be increased, but such will not be the case. For the complete wedges, not reaching down to the fluid mass, will not be immediately acted upon by it at all, and the truncated wedges, whose narrower sides are downwards, will be acted on by the fluid pressure with less force in proportion to their masses, than those of which the broader sides are downwards. These latter portions, therefore, will be more elevated than the others, and the whole will assume a position like that represented in the following diagram. When the wedges have assumed these positions, it



(2.)

* Whatever difficulty there may be in fully explaining the causes of such expansion, there can be no doubt of the existence of such causes in aggregations of matter in a state of fusion as here supposed. The intensity with which they may act is attested by actual volcanos, as well as by the masses which must have been ejected at former epochs, in a state of fusion.

† See memoir on Physical Geology, above referred to.

will be impossible for the mass to subside, when the elevatory force shall cease, into that position which it originally occupied. It will be formed into an arch capable (if its abutments be sufficiently strong) of entirely or partially supporting itself. Consequently, if the cause producing the intumescence of the fluid mass cease to act, and that mass return nearly to its original dimensions, the pressure of the superincumbent solid mass may, in the manner now described, be entirely or partially removed from the fluid. Hence, assuming that solidification is promoted by great pressure, it evidently appears how a portion of the interior mass might be maintained in a state of fluidity by the removal of a superincumbent pressure, which would otherwise have brought it to a state of solidity.

It is not here essential to suppose that the arch shall entirely support itself. It may be partly supported by the fluid beneath, or it may break down in certain points, or along certain lines, and form there new supports, intermediate to the extreme ones. Instead of one continuous internal lake, a number may thus be formed, connected with each other by more or less obstructed channels of communication, as I have supposed in the exposition of my theoretical views on the Elevation of the Wealden District, recently laid before the Geological Society. It is the existence of subterranean lakes under this form, which best enables us, as I conceive, to account for the observed phenomena of elevation.

10. The above view of the relative displacements of the different portions of an uplifted and disrupted solid mass, as resulting from its geological elevation, is strongly confirmed by its enabling us to account so completely for the law, first recognized by Mr. Phillips, and which I have myself verified in numerous instances, in the relative displacement of the beds on opposite sides of a fault. In diagram (2.) we observe that the line $f' g'$ is relatively depressed below $e f$, with which it was originally continuous; *i. e.* the beds are *lowest* on that side of the fault *towards* which the plane of the fault inclines from the vertical in *descending*. This precisely accords with the law above alluded to. It will be observed to hold at each of the faults represented in the diagram, and probably admits of fewer exceptions than almost any other law observable in the phenomena of elevation.

§. *Permanence in the Inclination of the Earth's Axis.*

11. To the conclusions above deduced from the investigations of my two preceding memoirs, I may add that of the permanence in the mean inclination of the earth's axis to the plane of the ecliptic. This permanence has been frequently insisted on, and is highly important with reference to our speculations on the causes of those changes of superficial temperature which certain geological phenomena seem so unequivocally to indicate. The proof, however, which has hitherto been given of this constancy of inclination has rested on the hypothesis of the entire solidity of the globe, an assumption which, whatever may be the actual state of our planet, can never be admitted as necessarily applicable to it at all past epochs of time, at which organic

forms may have existed on its surface. My previous investigations have now demonstrated the truth of this conclusion as applicable to the earth from the first formation of its external solid shell. All such hypotheses, therefore, as have sometimes been made with respect to a change in the position of the earth's axis are entirely excluded, whether we suppose the interior of the earth to be now, or to have been heretofore, solid or fluid. A fact also, in itself not uninteresting, is thus established in the earliest history of our globe.

Nor would it have been possible, I conceive, to arrive at this result by any general considerations immediately derivable from the nature of our problem, and independent of its complete solution. The investigations contained in my two preceding memoirs were, in fact, commenced under the impression that the solution of this problem of the precession and nutation of the earth's axis on the hypothesis of the interior fluidity of the earth, would probably lead to results different from those which had been long before obtained on the supposition of the earth's entire solidity. This impression was founded on the consideration of the great difference between the direct action of a force on a solid, and that on a fluid mass, in its tendency to produce rotatory motion. We have seen, in fact, that the disturbing forces of the sun and moon do not tend to produce directly any motion in the interior fluid, in which the rotatory motion causing precession and nutation, is produced indirectly by the effect of the above forces on the position of the solid shell. A modification is thus produced in the effects of the centrifugal force, which (as appears from the results of our investigations) compensates for the want of any direct effect from the action of the disturbing forces. This compensation will scarcely, perhaps, be deemed less curious than many of those which have been recognized in the solar system, and by which, amidst apparently conflicting causes, its harmony and permanency are so beautifully preserved.

§. *Condition respecting the Temperature of Fusion for the matter composing the Earth, in order that its actual Temperature may be due to its original Heat.*

12. There is also another conclusion to be drawn from our investigations which it may be worth while to notice. It has been assumed in these memoirs that pressure is effective in producing solidification; it has been already remarked, however, that should that not be the case, our conclusions respecting the thickness of the earth's crust will still, *à fortiori*, be true. Our determination, therefore, of the least limit to that thickness is independent of this unknown effect of pressure, or, in other words, of the experimental determination of the temperatures of fusion for different substances under high pressures. With the aid of a proper series of experiments on this point, a direct method of arriving at an approximation to the thickness of the crust of the globe, or rather, to its least limit, might be easily explained. I shall not here, however, enter into any discussion on this subject. The conclusion to which I would now direct attention is this—the present temperature of the interior of the earth cannot be due to its original heat, if the temperature of fusion for the matter composing

it be independent of the pressure to which the fused matter is subjected. For if the terrestrial temperature be due to that source, it must undoubtedly be sufficient at the depth of one-fortieth or one-fiftieth of the earth's radius, to fuse all the rocks composing the superficial solid portion of the globe placed under the atmospheric pressure. Consequently matter must exist at such depths in a state of fusion, and the crust of the earth must be extremely thin, unless its solidification has been promoted by pressure. I have shown, however, that the crust of the globe cannot be very thin, and therefore the truth of our proposition is manifest.

There is also another mode, independent of our results respecting precession, by which we arrive at the same conclusion. Making the assumption just stated respecting the origin of the actual terrestrial heat, there is no doubt of its being immensely greater at the earth's centre than that which would be necessary to reduce the matter composing the earth's surface, under the atmospheric pressure, to a state of fusion. It would probably reduce a large portion of it to a state of vapour. Now this actual central temperature must necessarily be at least something less than that which existed at the time of the earth's incipient solidification, whether the solidification commenced at the centre or surface (Mem. I.). If it began at the centre it must have been owing to the predominance of pressure in promoting solidification over high temperature in opposing it, and the truth of our proposition is therefore involved in this hypothesis. Again, suppose the solidification to have commenced at the surface. In this case it has been shown (Mem. I.) that the whole mass would arrive at that state in which the fluidity would just become imperfect, at nearly the same time. The superficial temperature would then be just that of *perfect fusion* under the atmospheric pressure for the matter constituting the earth's surface, which, as just stated, must be small compared with the actual central temperature, and, *à fortiori*, small compared with the central temperature at the epoch referred to. Consequently, at that epoch, the central and superficial parts of the earth, under widely different temperatures, would have the same degree of fluidity, viz. that at which it just became *imperfect*, or that at which the component particles would cease to move among themselves in the process of cooling. If then τ_1 denote the temperature of *perfect fusion* for a point of the earth's mass at any depth beneath its surface (or the temperature at which the mass would there acquire perfect fluidity), τ_1 must be some function of the pressure at the proposed point. Also let τ_2 denote the temperature of *incipient fusion* at the same point (or that at which the matter then under the same pressure would just lose its property of solidity), then the question is, whether τ_2 be a function of τ_1 or not. Now that there should be some necessary relation between τ_1 and τ_2 would scarcely seem to admit the possibility of a doubt. But in such case τ_2, being a function of τ_1, must depend on the pressure. Hence it follows, as before, that the temperature of fusion of the earth's mass must depend on the pressure to which it is subjected, assuming always that the fusibility of the matter composing the central portion of the globe is not extremely different from that which constitutes its surface.

IV. *On the Structure and Use of the Malpighian Bodies of the Kidney, with Observations on the Circulation through that Gland.* By W. Bowman, *F.R.S., Assistant Surgeon to the King's College Hospital, and Demonstrator of Anatomy in King's College, London.*

Received February 14,—Read February 17, 1842.

THESE remarkable bodies have been an object of much interest since their discovery by the great anatomist whose name they bear. Malpighi found they could be injected with great facility from the arteries, and he imagined them to be glands, in which the urine is elaborated from the blood. He seems also to have been of opinion that in them the uriniferous tubes take their rise*. Ruysch examined them with great care, and preserved specimens in his museum in which he believed that he had shown, by injection, that in them the arteries are continuous with the tubes†. This was the principal ground for the famous, but now exploded theory, of the existence of exhalant arteries with open mouths, which in the secreting glands opened directly into the excretory canals. It is probable that this accurate observer mistook the efferent vessel of the Malpighian body for a uriniferous tube, for the efferent vessels of those Malpighian bodies that lie near the medullary part of the kidney, take the same course as the tubes, and are often large enough to be readily mistaken for them. The statement, however, of Ruysch and others‡, that the tubes may be injected from the arteries, is true, though in a different sense from that in which they understood it.

Schumlansky§, some years afterwards, entertained more complete views of the connection between these bodies and the uriniferous tubes, and he has even given an ideal diagram of this connection, which shows that he had a very clear conception of the fact. From a considerable error, however, in the proportion of these bodies to the tubes (represented in his figure), it has been suggested that his description could not have been drawn from nature; a censure that seems to have been little merited.

* See his chapter "de internis glandulis renalibus, earumque continuatione cum vasis," a work not less conspicuous for the sterling accuracy of its observations than for the sagacity displayed in the reasonings based on them.

† "Quarum (gland. Malpigh.) nonnullæ hîc dissolutæ, in ductus Bellinos degenerant."—Ruyschius, Thesaurus Anat. x. No. 86. "Corpuscula rotunda et glandiformia in totum sunt dissoluta et extricata. Ductus qui dicuntur Bellini, in totum quoque repleti sunt propter repletionem arteriolarum."—Ibid. No. 149.

‡ Barnardus Albinus, after injecting the Malpighian bodies from the arteries, "vasa urinæ exinde prodeuntia eodem colore farta beatus conspexit."—Albinus, p. 63, 64. Vide Schumlanskii Dissert. Inaug. Anatomicam de renum structurâ. Argentorati, 1782, p. 69.

§ Schumlansky, *op. cit.*

Huschke* and Müller† are the only modern anatomists who have entered at length into this question, and they both deny that there is any connection between the Malpighian bodies and the uriniferous ducts. The assertions of Müller, in particular, are so positive, and are reiterated in so pointed a manner, that nothing but the most clear demonstration of their erroneous nature would have induced me to uphold an opposite opinion‡.

I was led to the examination of these bodies in the course of an inquiry into the ultimate structure of the true glands, in which I have been engaged for the last two years. I had frequently injected them from the artery, but had never inspected them under high powers of the microscope, until they arrested my attention while examining the structure of the uriniferous tubes. These tubes consist of an external tunic of transparent homogeneous tissue (which I have termed the *basement membrane*), lined by epithelium. The Malpighian bodies I saw to be a rounded mass of minute vessels invested by a cyst or capsule§ of precisely similar appearance to the basement membrane of the tubes. Seeing these similar tissues in such close proximity, it was not easy to resist the conviction that the capsule was the basement membrane of the tubes expanded over the vessels, but, after many trials, I could not at that time succeed in gaining an unequivocal view of their continuity. All that I could accomplish was to perceive here and there an ambiguous approach to such an arrangement, sufficient to make it appear probable.

I should perhaps have relinquished the idea thus presented to my mind, had not accident again drawn me to it. Having, during last summer, been made acquainted, through the kindness of Dr. Milne Edwards, with a new method of injection employed with great success by M. Doyère of Paris‖, I injected some kidneys through the artery, by this method, in order to notice the nature of the vascular ramifications in the Malpighian bodies. I not only found what I sought, but the clearest evi-

* Huschke, Ueber die Textur der Nieren. Isis, 1828, p. 561.

† Joh. Müller, de Glandularum secernentium structurâ penitiori. Lipsiæ, 1830, lib. x.

‡ Huschke says (quoted by Müller), "These corpuscles (Malpighian bodies) are without any connection with the uriniferous ducts. For these most distinctly terminate by free blind extremities, while the Malpighian bodies, everywhere scattered in the interstices of the tortuous uriniferous ducts, are only connected with the blood-vessels."—Müller, *loc. cit.*, p. 87.

Müller says, "Attamen certissimum est, ex vasis sanguiferis, ductus uriniferos planè nunquam usquam repleri, massamque injectam ne quidem laceratione in tubulos uriniferos prorumpere," *op. cit.*, p. 98. "Fines ductuum uriniferorum in corpora Malpighiana desinere, certissimè falsa assertio est," p. 95. "Falsissima est opinio de connexu ullo quopiàm inter corpora Malpighiana sanguifera, et ductuum uriniferorum fines," p. 95. And other passages equally strong might be quoted.

§ First particularly pointed out by Müller, who conceives it to be perfectly closed, except at one point where perforated by the vessels.

‖ This consists of two fluids which mingle in the small vessels, and cause a precipitation there. The best fluids are saturated solutions of bichromate of potass and of acetate of lead. They are injected in succession through the same vessel, whence the method is termed that by *double injection*. Krause published an account of it two years ago, but M. Doyère appears to have arrived at it after a laborious trial of numerous solutions. Both deserve the thanks of anatomists for so valuable an addition to the means of investigation.

dence that the capsule which invests them is, in truth, the basement membrane of the uriniferous tube expanded over the tuft of vessels. The injected material had, in many instances, burst through the tuft, and, being extravasated into the capsule, had passed off along the tube. I have since made numerous injections of the human kidney, and of that of many of the lower animals, and in all, without exception, have met with the same disposition. I have also repeated, with better success than before, the examination of thin slices of the recent organ with high powers of the microscope, and in this manner have fully corroborated the evidence furnished by injections. This mode of examination has likewise led to the interesting discovery of ciliary motion within the orifice of the tube.

According to my own observations, the circulation through the kidney may be stated to be as follows:—All the blood of the renal artery (with the exception of a small quantity distributed to the capsule, surrounding fat, and the coats of the larger vessels) enters the capillary tufts of the Malpighian bodies; thence it passes into the capillary plexus surrounding the uriniferous tubes, and it finally leaves the organ through the branches of the renal vein. Following it in this course, I shall now endeavour to describe the vascular apparatus, and the nature of its connection with the tubes.

With the inconsiderable exceptions just mentioned, the terminal twigs of the artery correspond in number with the Malpighian bodies. Arrived here*, the twig perforates the capsule, and, dilating, suddenly breaks up into two, three, four, or even eight branches, which diverge in all directions like petals from the stalk of a flower, and usually run, in a more or less tortuous manner, subdividing again once or twice as they advance, over the surface of the ball they are about to form. The vessels resulting from these subdivisions are capillary in size, and consist of a simple, homogeneous, and transparent membrane. They dip into its interior at different points, and after further twisting, reunite into a single small vessel, which varies in its size, being generally smaller, but in some situations larger than the terminal twig of the artery. This vessel emerges between two of the primary divisions of the terminal twig of the artery, perforating the capsule close to that vessel, and, like it, adhering to this membrane as it passes through. It then enters the capillary plexus which surrounds the tortuous uriniferous tubes†.

The tuft of vessels, thus formed, is a compact ball, the several parts of which are held together solely by their mutual interlacement, for there is no other tissue ad-

* As the mode of subdivision of this artery in the interior of the organ is well known, I have omitted to describe it. Its branches never anastomose. It almost invariably happens that the twigs ending in the Malpighian bodies are of considerable length, but occasionally (as in fig. 8) two bodies are sessile on very short twigs of a single branch.

† "Cæterùm glomeruli ulterior conformatio in præstantissimis quamvis injectionibus non facilè extricari potest. Videor tamen observasse arteriolam, quæ glomerulo accedit, cirri adinstar dividi, unde tortuosa vascula oriuntur, quæ ansis secum arctè connectuntur et recurrunt. Sed hoc certum est, glomerulos liberè in vesiculis contineri, nec ullibi, nisi uno in puncto, cum vesiculis cohærere."—Müller, *loc. cit.*, p. 101.

mitted into the capsule besides blood-vessels. It is subdivided into as many lobes as there are primary branches of the terminal twig or afferent vessel, and these lobes do not communicate, except at the root of the tuft. There are, therefore, deep clefts between them, which open when the lobes are not greatly distended with injection or blood. The surface of the tuft is everywhere unattached and free, and continuous with the opposed surfaces of the lobes. The whole circumference of every vessel composing the tuft, is also free, and lies loose in the cavity of the capsule. These circumstances cannot be seen in specimens gorged with injection, but only by careful examination of recent specimens with a power of 200 or 300 diameters. The vessels are so perfectly bare, that in no other situation in the body do the capillaries admit of being so satisfactorily studied. It is only where the tuft is large, as in Man and in the Horse, that its lobulated character can be always discerned. When the number of primary subdivisions of the afferent vessel is smaller, the detection of lobes is less easy. They may often be seen, however, in the Frog. In Birds and Reptiles, the afferent vessel seldom divides, but dilates, instead, into a pouch-like cavity, which, after taking two or three coils, contracts again and becomes the efferent vessel. Here of course there are no lobes; but the surface of the whole dilated part is free.

The basement membrane of the uriniferous tube, expanded over the Malpighian tuft to form its capsule, is a simple, homogeneous, and perfectly transparent membrane, in which no structure can be discovered. It is perforated, as before stated, by the afferent and efferent vessels, and is certainly not reflected over them. They are united to it at their point of transit, but in what precise manner I have not been able to determine. Opposite to this point is the orifice of the tube, the cavity of which is continuous with that of the capsule, generally by a constricted neck. I have specimens prepared with the double injection showing this continuity in Mammalia, Birds, Reptiles and Fish; and, in Mammalia and Reptiles, I have obtained the still more satisfactory proof afforded by a clear view of the whole of the textures magnified 300 diameters. As the Malpighian bodies are placed in every possible direction, it often happens that a thin section, parallel to the neck of the tube, cannot at once be obtained: but with perseverance this may always be done. The capsule is then seen to pass off into the basement membrane of the tube, as the body of a Florence flask into its neck. The basement membrane of the tube is lined by a nucleated epithelium of a finely-granular opake aspect, while the neck of the tube and its orifice become abruptly covered with a layer of cells much more transparent, and clothed with vibratile cilia. The epithelium is continued in many cases over the whole inner surface of the capsule; in other instances I have found it impossible to detect the slightest appearance of it over more than a third of the capsule. When fairly within the capsule, the cilia cease, and the epithelium beyond is of excessive delicacy and translucence. Its particles are seldom nucleated, and appear liable to swell by the addition of the water added to the specimen. They frequently fill up the space between the capsule and tuft, and touching the latter, may seem to be united to it.

The lines of their mutual contact may then wear the aspect of a highly delicate areolar tissue, connecting the capsule with the tuft. The cavity existing in the natural state between this epithelium and the tuft, is filled by fluid, in which the vessels are bathed, and which is continually being impelled along the tube by the lashing movement of the cilia. In the Frog, where alone I have as yet been able to see these wonderful organs in motion, they were longer than those from other parts of that animal, and extremely active.

The tubes, on issuing from the Malpighian bodies, invariably become greatly contorted. I have on one occasion seen two of them unite, and from their dichotomous mode of division, when traced up from the pelvis, there can be little doubt that this is constantly their disposition. I have never, in all my examinations, met with any appearance of an inosculation between different tubules. The tortuous tubes unite again and again in twos, and finally, under the name of pyramids of Ferrein, become straight, and converge towards the pelvis, forming the medullary cones or pyramids of Malpighi. The Malpighian bodies are imbedded in a kind of nidus formed among these convolutions, and are touched on all sides by the surrounding tubes. As the emergence of the tube from the Malpighian body can be seen only at one point, it is not wonderful that it should have been overlooked, and that the demonstration should have seemed clear, that the Malpighian bodies merely lie among the tubes, and have no connection with them.

The blood, leaving the Malpighian tufts, is conveyed by their efferent vessels to the great renal reservoir, the capillary plexus surrounding the uriniferous tubes. This, in its general arrangement, resembles that investing the tubes of the testis. The vessels lie in the interstices of the tubes, and everywhere anastomose freely, so that throughout the whole organ they constitute one continuous network, lying on the outside of the tubes, in contact with the basement membrane. This plexus is interposed between the efferent vessels of the Malpighian bodies and the veins.

The efferent vessels of the Malpighian bodies are always solitary and never inosculate with one another: each one is an isolated channel between its Malpighian tuft, and the plexus surrounding the tubes. They are formed by the union of the capillary vessels of the tuft, and emerge from its interior in the manner already explained. After a course of variable length they open into the plexus. Their size is various. In general, they are smaller than the terminal twig of the artery, and scarcely, if at all, larger than the vessels of the plexus into which they discharge themselves. But where the Malpighian tuft is large, the efferent vessel is usually large also, and divides into branches before entering the plexus. This is eminently the case with those situated near the base of the medullary cones, where the medullary and cortical portions of the organ seem to blend. The efferent vessels from these large Malpighian bodies are often three or four times the diameter of those of the plexus, and take a course towards the pelvis of the kidney between the uriniferous tubes. They were formerly mistaken for tubes. They branch again and again in the manner of arteries,

and form the plexus with long meshes which invests this part of the tubes. Some of the veins springing from this plexus form the well-known network on the nipple-shaped extremities of the cones, around the orifices of the tubes, and thence take, with the remainder, a backward course, likewise parallel to the tubes, to empty themselves into venous branches that lie about the bases of the cones. These also, when injected, have been mistaken for tubes.

The other venous radicles are dispersed at about equal distances throughout the cortex of the kidney, and each receives the blood on all sides from the plexus surrounding the convoluted tubes. When these venous radicles are congested, or injected, they mark out the surface of the cortical substance into lobules not very unlike those of the lobules of the liver. On the Horse's kidney, especially, this may be often well seen. Each lobule contains many tortuous ducts with their capillaries, but the convolutions of any one duct are not confined to a single lobule. These radicles unite in an irregularly arborescent figure, anastomose and form the several branches of the renal vein. Those on the surface, especially of the human kidney, have a tendency to converge towards a central vessel which then dips into the interior, and runs, like the rest, towards the hilus. Thus are formed the stellated vessels of anatomists, often conspicuous in diseased specimens. Between the sprawling arms of these stellæ the convoluted tubes, with their plexus, come up to the surface (Plate IV. fig. 11), but the Malpighian bodies are rarely, if ever, visible quite on the surface. They are always covered in by convolutions of the tubes.

The veins from the capsule and surrounding fat join the renal vein in some part of its course. It is probable that the capillaries of the vasa vasorum, within the substance of the organ, pour their blood into the capillary plexus surrounding the tubes, as those of the hepatic artery do into the portal-hepatic plexus of the lobules of the liver.

Thus there are in the kidney *two perfectly distinct systems of capillary vessels*, through both of which the blood passes in its course from the arteries into the veins: the 1st, that inserted into the dilated extremities of the uriniferous tubes, and in immediate connection with the arteries; the 2nd, that enveloping the convolutions of the tubes, and communicating directly with the veins. The efferent vessels of the Malpighian bodies, that carry the blood between these two systems, may collectively be termed the *portal system of the kidney*. To these distinct capillary systems, I am inclined to attribute distinct parts of the function of the organ; and their importance seems to warrant a few words, in further explanation of their anatomical differences.

The former, which may be styled the Malpighian capillary system, is made up of as many parts as there are Malpighian bodies. These parts are entirely isolated from one another; and, as there is no inosculation between the arterial branches supplying them, the blood enters each in a direct stream from the main trunk. This capillary system is also highly remarkable, indeed stands alone among similar structures, in being *bare*. The secreting tubes of the kidney, like those of all other glands, are,

strictly speaking, an involution of the outer tegument of the frame: their interior is, in one sense, the outside of the body: their walls intervene between the vessels and the exterior, and, as it were, cover them in. But here is a tuft of capillaries extruded through the wall of the tube, and lodged in a dilatation of its cavity, uncovered by any structure. Bare indeed, yet screened from injury in its remote cell, with infinite care and skill! Each separate part, also, of this system, has but one afferent and one efferent channel, and both of these are exceedingly small, compared with the united capacity of the capillary tuft. The artery in dividing, dilates: then follow branches which often exceed it in size, and which gradually break up into the finest. The efferent vessel does not usually even equal the afferent, and in size is often itself a capillary. Hence must arise a greater retardation of the blood in the tuft, than occurs probably in any other part of the vascular system; a delay that must be increased by the tortuosity of the channels to be traversed.

The other system of capillaries, or that surrounding the uriniferous tubes, corresponds, in every important respect, with that investing the secreting canals of other glands. It is well known to anatomists, and therefore does not require to be described at any length. Its vessels anastomose with the utmost freedom on every side, and lie on the deep surface of the membrane that furnishes the secretion.

I have applied the term '*portal system of the kidney*' to the series of vessels connecting these two, on account of the close analogy it seems to bear to the vena porta. The precise quality of the blood it carries may be doubtful, but in distribution it is similar. It intervenes between two capillary networks, the first of which answers to that in which the vena porta originates, and the second to that in which the vena porta terminates. The obvious difference lies in its several parts not uniting into a single trunk, to subdivide afterwards; but this circumstance seems to admit of an easy explanation. A trunk is formed in the great portal circulation, for the convenience of transport, most of the capillaries which supply it lying at a distance from the liver. Some, however, viz. those drawn from the hepatic artery, either enter the portal-hepatic plexus directly, (as Müller thinks, and as my preparations certainly show some of them to do,) or else join the minuter twigs of the portal vein, according to the opinion of Kiernan. Now, in the kidney, the vessels issuing from the Malpighian tufts are disseminated pretty equally throughout the plexus surrounding the tubes (the one into which they have to discharge themselves), and they therefore enter it at all points at once, without uniting. In the medullary cones, however, where there is a capillary plexus to be supplied with blood, but no Malpighian bodies nearer than the base of the cones, the conditions which oblige the formation of a portal venous trunk begin to operate; the two capillary systems it serves to connect are at some distance apart. Here, consequently, the Malpighian bodies are generally larger, their efferent vessels more capacious, and branched after the manner of an artery. *Each one of these efferent vessels is truly a portal vein in miniature.*

The capillary plexus surrounding the tubes differs, therefore, from that of other glands, and agrees with that of the liver, in its receiving blood that has previously traversed another system of capillary vessels. That other system is a peculiar one, as already pointed out, and cannot be likened closely to that which furnishes the portal vein of the liver.

The preceding account of the existence of a true portal system in the kidney of the higher tribes of Vertebrata was already written, when an opportunity presented itself of inspecting the distribution of the vessels in one of those lower animals, in which, besides the renal artery, the kidney is furnished with a portal vein, derived from the hinder part of the body. The presence of such a vein, though denied by MECKEL, was well established by NICOLAI, whose statements have been confirmed by others; but I am not aware that any anatomist has explained its remarkable distribution, and its connection with the other vessels*. I shall therefore introduce a summary account of my examination of the kidney of the Boa Constrictor (the animal in question), which may be regarded as a model of this variety; and I think it will be found not only to show the correctness of the analogy I have drawn between the efferent vessels of the Malpighian bodies and a portal system, but to place in a clearer light the other striking resemblances between the circulation of the liver and kidney.

The kidney of the Boa, being composed of isolated lobes, of a compressed reniform shape, displays all the points of its structure in peculiar simplicity and beauty. At what may be termed the hilus of each lobe, the branches of the vena porta and duct separate from those of the renal artery and emulgent vein; the two former spreading side by side, in a fan-like form, over the opposite surfaces of the lobe, while the two latter enter its substance, and radiate together in a plane midway between these surfaces. The lobe is made up of the ramifications of these four sets of vessels, in the following mode. Each *duct*, as it runs over the surface, sends down a series of branches which penetrate in a pretty direct manner towards the central plane. Arrived there, they curl back, and take a more or less retrograde course towards the surface, and finally, becoming more convoluted, terminate in the Malpighian bodies, which are all situated in a layer at some distance within the lobe, parallel to the central plane, and nearer to it than to the surface. The ducts never anastomose. The *artery* subdivides into extremely minute twigs, no larger than capillaries, which diverge on either hand, and enter the Malpighian bodies. The efferent vessels are of the same size as the afferent, and on emerging, take a direct course to the surface of the lobe, and join the branches of the vena porta there spread out. The branches of the *portal vein* on the surface, send inwards a very numerous series of twigs of nearly uniform capacity, and only a little larger than the vessels of the *capillary plexus*, in which

* HUSCHKE, who seems to have entered into the greatest detail on this subject, states that he was unable to ascertain in the Serpent's kidney, whether the twigs of the artery were distributed to the Malpighian bodies or not. In the Frog, however, he describes the Malpighian bodies as appended to the terminal twigs of the artery. Isis, 1828, p. 566–7.

they almost immediately terminate. This is the plexus surrounding the uriniferous tubes. It extends from the surface to the central plane of the lobe, and there ends in the branches of the *emulgent vein.*

Thus the efferent vessels of the Malpighian bodies are radicles of the portal vein, and, through the portal vein, empty themselves, as in the higher tribes, into the plexus surrounding the uriniferous tubes. The only real difference between this form of kidney and that of Mammalia, is, that there is here a vessel bringing blood that has already passed through the capillaries of distant parts, to be added to that coming from the Malpighian bodies, and to circulate, with it, through the plexus surrounding the tubes. The efferent vessels of the Malpighian bodies run up to the surface in order to throw their blood through the whole extent of the capillary plexus; which they would fail to do, if they entered it in any other part.

I have described the renal artery as being spent upon the Malpighian bodies; but in the hilus of the lobe it gives off, as in the higher animals, a few slender twigs to the coats of the excretory ducts and of the larger vessels. The capillaries of these twigs are easily seen, and, in all probability, discharge themselves into the branches of the portal vein.

The circulation through this form of kidney, may be aptly compared with that through the liver, as described by Mr. Kiernan in his invaluable paper on that gland. The plexus surrounding the tubes corresponds with the portal-hepatic plexus, which, in the lobules of the liver, invests the terminal portions of the bile-ducts. Both these plexuses are supplied with blood by a portal vein, derived chiefly from the capillaries of distant organs, but in part from those of the artery of the respective organs themselves. The only difference seems to be, that, while, in the liver, the branches of the artery are entirely given to the larger blood-vessels, ducts, &c., in the kidney, a few only are so distributed, the greater number going through the Malpighian bodies, to perform an important and peculiar function. In both glands, however, all the blood of the artery eventually joins that of the portal vein. The emulgent vein of the kidney answers to the hepatic vein of the liver.

The *comparison between the hepatic and renal portal circulation* may be thus drawn in more general terms. The portal system of the liver has a double source, one extraneous, the other in the organ itself: so, the portal system of the kidney, in the lower tribes, has a two-fold origin, one extraneous, the other in the organ itself. In both cases the extraneous source is the principal one, and the artery furnishing the internal source is very small. But in the kidney of the higher tribes, the portal system has only an internal source, and the artery supplying it is proportionally large.

The above account appears to me to comprise whatever is most important in the anatomy of the blood-vessels and ducts of the kidney. My object in it has been to convey an idea of the physiological anatomy of the gland, and I have therefore omitted to mention (except where it suited my purpose) those rougher characters of the kidney in the various classes, that result from varieties in the mode of aggregation of

its several constituent parts. The principal of these are well known, and it would have diverted attention too much to delineate others, especially as such peculiarities are of trifling moment. The accompanying illustrations I have endeavoured to execute with scrupulous fidelity after nature. The injected specimens from which several of them are taken, are, with numerous others, in my possession, and those that can be examined only in a recent state, may usually be prepared with facility.

I shall now state the results of my injections of the kidney of Man and the higher animals by the arteries, veins, and ducts, in order to show their accordance with the view I have given of the nature of the Malpighian bodies, and of the vascular apparatus of the organ. This may be also desirable for purposes of comparison with the statements of other anatomists (which, to avoid prolixity, I have not referred to in detail); and it will, besides, give a full opportunity of testing the correctness of my statements, to those inquirers who may be disposed to do so*.

By the Arteries, *the Malpighian Tufts can be injected with great facility, and also, with less freedom, the Capillaries surrounding the uriniferous tubes. The Tubes also may be injected, by extravasation from the Malpighian tufts.*

The course of the injection to the tufts is direct and free. The arterial tree is of small capacity, and there is seldom so much blood in it after death as to impede the flow of the artificial fluid. My preparations show this tree injected in various degrees, by the double fluid (Plate IV. figs. 1 to 14). In some, the tufts are full, the afferent and the efferent vessels are both seen, as well as the communication of the latter with the plexus surrounding the tubes (figs. 2, 4, 5, 6). In others, the vessels of the tuft have given way under the pressure of the fluid, which has then escaped into the capsule and often into the tube also† (figs. 4, 9, 10, &c.). Sometimes the injection has passed freely and without extravasation through only a portion of the Malpighian tuft, leaving the rest filled with blood, which could not have happened to an unbranched coil of vessel, as this tuft is by some described‡. In these, the afferent and the efferent vessels are both injected, but only a fragment of the tuft (fig. 2). Sometimes the injected fluid has burst out immediately on entering the first branches

* It is worthy of notice, as showing both the difficulty of the subject and the uncertain state of our knowledge up to the present time, that Berres, the distinguished Professor of Vienna, in his recently published work on microscopical anatomy, maintains the existence of a direct inosculation of the uriniferous tubes with the capillary plexus surrounding them. After the description already given, I need hardly say, that this view seems to me, for many reasons, altogether untenable.

† I have great pleasure in stating that my friend Mr. Tomes, three years ago, during his examination of numerous kidneys that he had injected, saw two or three examples of this escape of the injection along the tube; of one of which he has preserved a rough outline. Not being able to see it again he gave up the search. I have no doubt that he communicated this fact to me in conversation at the time, though I cannot now recollect his doing so. The first drawing I made of the tube expanded over the tuft, I find dated February 17, 1841; about which time my interest in the subject was first excited.

‡ Of course this never occurs in Birds, where the Malpighian vessel is a coiled ampulla.

of the tuft: it has then insinuated itself between the ball of vessels and the capsule, and has run off along the tube. In this case the tuft is left uninjected and containing blood, and it becomes enveloped in a film of injection (fig. 9). Sometimes one side only of the tuft is injected at the moment when extravasation occurs, sometimes the whole, and likewise the efferent vessel (figs. 3, 4). In general, the capsule, when thus filled with extravasated injection, has a perfectly smooth external surface, but when the tuft within is also much distended, this may, in the dried and somewhat collapsed specimen, give to the outer surface of the capsule an uneven appearance like that of the tuft itself. The capsule, when distended, is seen in many instances to bulge and form a prominent circle round the point at which the vessels enter and emerge. The vessels then appear to lie in a small pit or fissure before becoming connected with the tuft (fig. 9). Lastly, it occasionally happens that though extravasation has occurred into the capsule, the fluid has not spread itself over the whole surface of the tuft, and yet has passed off along the tube (figs. 3, 10, *m*, *m*). As the tubes in the human kidney usually become very tortuous immediately on leaving the Malpighian bodies, the injection running off along them may often wear the appearance of an irregular extravasated mass, and so its real nature escape observation*

* During the course of the researches detailed in this paper, I have embraced whatever opportunities presented themselves of studying the morbid conditions of the human kidney, and especially those usually known as the stages of Bright's disease. It would obviously have been little conducive to my present purpose to have entered here upon a general description of the results to which my inquiries on this interesting subject have led me, but I cannot forbear noticing one fact of considerable importance, which will both illustrate and be illustrated by the preceding account of the normal anatomy of the gland. It is well known that blood is often passed with the urine during the course of the disease, especially at the earlier periods of it, when many circumstances contribute to prove that the kidneys are in a state of sanguineous turgescence. How does this blood escape into the ducts of the gland? The organ examined at this time presents on its surface and throughout its cortical substance, scattered red dots, of somewhat irregular shape, not accurately rounded, and generally as large as pins' heads, that is, very many times larger than the Malpighian bodies. These spots are very visible on the surface, where, as I have before stated (p. 62), no Malpighian bodies exist. They have been nevertheless described by several recent writers (not without contention for the honour of the discovery) as Malpighian bodies enlarged from congestion. How a Malpighian tuft, such as I have described it, could attain so prodigious a bulk, prodigious compared with its natural size, it would not be easy to explain. It is true that, if examined with a lens, the blood forming these spots is found to be arranged in convoluted lines, but these convolutions are not the dilated vessels of the tuft. They are nothing less than *the convolutions of a tube filled with blood,* that has burst into it from the gorged Malpighian tuft at its extremity. This is at once evident to a person familiar with the appearance of the same tubes when filled with injection in a similar manner; and the figure, which I have taken from a healthy kidney so injected (fig. 11), might serve as an exact representation of one of these spots, as seen on the surface of the diseased organ. The more or less perfect plug, thus often formed in the tubes, is the occasion of those dilatations of the *tubes* and Malpighian *capsules,* which are to be met with in the more advanced stages of the disease. Thus is to be explained the somewhat loose statement, that the disease consists essentially in enlargement of the Malpighian bodies. Though I have examined with great care many kidneys at all stages of the complaint, I have never seen, in any one instance, a clearly dilated condition of the Malpighian tuft of vessels. On the contrary, my friend, Mr. Busk, an excellent observer, has specimens which undoubtedly prove these tufts not to be dilated in the first stage, and I possess injected specimens showing them at all stages, but never above their natural size. I am far from implying,

(fig. 9). When size and vermilion are employed, this is very apt to occur*, and especially when the specimen injected is not fresh; for the epithelium soon loses its adhesion to the basement tissue of the tube, and, falling into the cavity, mingles with the stream of injection, and renders its course obscure. This lining of the tubules with a pavement of epithelium occasions a striking appearance in perfectly fresh specimens, when filled with double injection. This penetrating material insinuates itself into the interstices of the epithelial particles, and thus marks them out as a kind of pattern on the wall of the tube. When extravasation does not take place in the Malpighian bodies, more or less of the network surrounding the tubes is not unfrequently injected. The most perfect specimens of injected Malpighian tufts are then obtained; but the veins themselves are seldom well filled through the arteries, for not only is the way to them circuitous, and broken up into a thousand separate avenues (the Malpighian tufts), but it is usually loaded with blood. When injection is driven into any one branch of the renal artery, the several states now detailed are seen only in the parts to which that branch is distributed. There is no anastomosis between the branches in the interior of the gland.

It sometimes happens that in injections by the artery, extravasation is found to take place into the interstices of the tubes, with or without escape into the Malpighian capsules and tubes. This may arise from rupture either of the arterial tree, before reaching the Malpighian bodies (which is uncommon, where great force is not employed), or of the efferent vessels of those bodies, or of the network of the tubes, injected through them. It may also occur from rupture of a tube, which has been itself filled by the rupture of a Malpighian tuft.

By the Veins, *the Capillaries surrounding the tubes may be injected, but neither the Malpighian bodies, nor the arteries, nor, without extravasation, the tubes.*

The capillaries of the uriniferous tubes are of great aggregate capacity, and commonly contain much blood. When injection is pushed into the vein the whole organ instantly swells; so rapidly do these dilatable and freely inosculating channels receive the fluid impelled into them. By the numerous communications of the capillaries with the veins, it is at once dispersed in every direction, and enters the capil-

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however, that these bodies are unconcerned in the train of morbid phenomena. They unquestionably are so, and even necessarily must be so, from their anatomical structure, but in what manner I shall not at present attempt to show.

* My friend Mr. Quekett, of the College of Surgeons, possesses many very excellent specimens of injected kidneys, in many of which he has been able to detect the tube passing from the Malpighian body, since his attention was directed to this arrangement. He also showed me a very beautiful injection of the Malpighian bodies in the Horse, sent over to the Microscopical Society of London by Prof. Hyrtl of Prague. In one corner of this we found a similar extravasation, though the disposition in question seems to have eluded the attention of that excellent anatomist. I am indebted to Mr. Quekett for some finely injected specimens of a boa's kidney, from one of which fig. 14. is taken.

laries by innumerable avenues. But towards the Malpighian bodies, there is no opening from this capillary network at all corresponding in magnitude or freedom to that on the side of the veins. In fact, the only points by which it can discharge itself are the efferent vessels of the Malpighian bodies, which are comparatively few in number, only capillary in size, and quite disconnected with one another, except through the plexus itself. Add to this, that the Malpighian tuft to which they lead is a great obstacle to the passage of fluid, from the tortuosity of its minute vessels, and by their all having but one point to discharge themselves of the blood they already contain, viz. their afferent vessel. Thus to fluid driven through the kidney in a retrograde course, there is not only the general impediment offered by the aggregate capacity of the arteries being greatly inferior to that of the veins, but a vascular arrangement equivalent to a double valve. The capillaries of the tubes form a first great cul-de-sac, those of the Malpighian tufts a second, for these may both be described as great reservoirs, easily entered from the side of the arteries, but discharging themselves with great difficulty back again, or towards the arterial tree. If it be now considered that the network of the tubes, or the former and far the greater of these reservoirs, almost always retains much blood after death, and that the Malpighian reservoir is never without a considerable quantity, it will not be difficult to comprehend, why injection thrown into the veins reaches not to the Malpighian bodies, however well it may seem to load the capillaries of the tubes; for all the blood must first pass through the difficult channels that have been spoken of, and this it never can do completely. I suppose that this view of the subject, which is nothing more than a statement of facts, will be deemed a sufficient explanation, and that it will not be regarded as necessary to imagine the existence of real valves in any part of the course of these small blood-vessels. I have never met with any appearance that could lend credibility to such a supposition, which, if true, would present an unique structure in the vascular system. Extravasation from the veins will sometimes reach the tubes, in consequence of a structure which will presently be explained.

By the Tubes, *the Malpighian bodies cannot be injected, nor, without extravasation, either the plexus surrounding the tubes, or the veins.*

Many anatomists have taken extreme pains to inject the tubes from the pelvis of the kidney, by means of the air-pump, but never has a single Malpighian body been thus filled. This, it has been said, is a conclusive proof that the Malpighian bodies are not placed at the extremities of the tubes. But I think that if the real structure and relation of these parts be duly considered, this constant result will be allowed to be in the strictest accordance with the account I have delivered, and even a necessary effect of the anatomical disposition of the parts. To those who are acquainted with the practical difficulties of the injection of the ducts of glands in general, and especially of those which are very tortuous, the following considerations on this subject

will probably appear conclusive. Even of the testis (where the tubes are far thicker and stronger in their coats, and much more capacious than in the kidney), there are not ten specimens that can be pronounced at all full, in the museums of Europe; and there is no evidence, that, even in the best of these, the injected material has reached the very extremities of the tubes.

In the kidney, the tubes are exceedingly tortuous after leaving the Malpighian bodies, and only become straight, in most animals, in proceeding towards the excretory channel to discharge themselves. The way towards their orifices is so free, in a natural state, that their fluid contents exert no distending force upon their walls. Accordingly their walls are exceedingly feeble; the basement membrane on which their strength mainly depends, is very delicate and easily torn. They are therefore incapable of offering much resistance to a fluid impelled into them from the pelvis, but burst readily, if it be forcibly urged. But were the coats ten times as tough as they really are, injection could not penetrate far into their convoluted portion, unless pushed with much force; and this for two reasons:—1st. The fluid which the tubes already contain has no means of escape before the injection, since these canals end by blind extremities in the Malpighian bodies; and though these bodies are dilatations of them, yet they are already filled almost completely by the tuft of capillaries, and offer no capacious receptacle for the fluid from the tubes. 2nd. The layer of epithelium (which usually forms about two-thirds of the thickness of every tube, the calibre being about one-third*) is, immediately after death, very prone to separate from the basement membrane which it lines, and to fall into and block up its narrow channel. Even if the epithelium remains in its place, the calibre of the tube is but small, and if it becomes detached, it opposes an effectual bar to the progress of the injection. By removing the pressure of the atmosphere from the outer surface of the tubes, these obstacles are occasionally in part overcome, so that even the tortuosities of the tubes are filled for a certain distance. But even so limited a success is rare, and in face of mechanical obstacles, such as above mentioned, to the onward current of the injection in the tubes, the force employed invariably sooner or later bursts their coats, ere their extremities have been reached. Extravasation from the tubes, as might be expected, fills their interstices, and the fluid may then issue by a rent at the hilus of the kidney. But it is remarkable how readily it enters the veins and absorbents from the ducts. This is undoubtedly by extravasation, and does not prove any continuity between them. The veins may be filled when the fluid has not penetrated in the tubes beyond the medullary cones, showing that the rupture must occur in connection with those cones, either at their apices or in their substance. By a thin transverse section of one of these cones, the ducts and blood-vessels of which they principally consist, are seen to be imbedded in a sort of matrix, apparently homogeneous, but probably having a cellular structure. This matrix keeps the tubes and

* These proportions vary considerably. The basement membrane is so thin that it may be left out of the estimate.

vessels open by being united to their outer coat, whence results the dark colour, usually attributed to congestion, which these cones commonly present, as compared with the cortical part, where this matrix is less abundant. This is the structural condition which seems to me most easily to explain the remarkable facility with which injection, urged along the tubes, enters the veins. The smallest rupture of the matrix will crack across the minute vessels accompanying the tubes, and expose their open extremities to the entrance of the injection. If the force employed be very moderate and equable, extravasation does not occur, and the tubes alone are injected, often to the surface, but undue or ill regulated pressure almost inevitably occasions it. Having once entered a small vein, through however small an opening, it soon diffuses itself through the veins, and the capillaries surrounding the tubes, rather than along the tubes, for the reasons above stated; and, if the organ be then cut to pieces and examined, these vessels seem filled, without extravasation; the tubes are also more or less filled with the same colour; and the two structures are so intricately interlaced, as to wear the aspect, especially if dried, of one continuous network. The point of extravasation escapes observation, and hence the fallacy of imagining a continuity between the veins or their capillaries, and the tubes.

Some distinguished anatomists have held that the tubes end in a plexiform manner, and have stated themselves to have unequivocally seen this arrangement in injected specimens. I am induced to believe this opinion to be founded on deceptive appearances; either such as that above mentioned, or that occasioned by the overlapping of injected tubes. Others have considered the tubes to terminate in free blind extremities unconnected with the Malpighian bodies, and have likewise rested their opinion on the appearances of injected specimens, as well as on those of recent ones. As the injection always stops short of the real extremities of the tubes (the Malpighian bodies), it must necessarily show apparent free extremities—and others may be produced by the section requisite for the examination of the part. As for the false appearances presented by recent specimens, they are obviously referable to the sudden bending down of a tube behind the part turned to the observer. In a mass composed of convolutions, many such must continually occur; and their real nature may be easily determined by the use of a high power and varying focus. Other anatomists, aware of this last fallacy, and failing to find either a free inosculation of the tubes in the form of a plexus, or a termination of them in the Malpighian bodies, have rested in the conclusion that the curves of the convoluted part are the looped junctions of different tubes. It is obvious that this conclusion is a deduction drawn from the apparent absence of any other mode of termination, and must be relinquished now that the tubes are shown to end in the Malpighian bodies.

The foregoing account has been drawn principally from my observations on the kidneys of Mammalia, but it is intended to embrace the chief points in the anatomy of the Malpighian bodies in all the Vertebrate tribes. In all these, I have ascertained

the Malpighian body to consist of the dilated extremity of the uriniferous tube, with a small mass of blood-vessels inserted into it. But in the several orders of animals, there are various modifications that merit notice. The most considerable of these regard the size of the Malpighian bodies, in connection with which are others in the mode of division of the arterial twig. The following Table exhibits this variety in their size, in a few species, and subjoined to each measurement, is that of the tube soon after its emergence. It will be seen that the tubes differ far less than the Malpighian bodies.

Table of the Diameter of Malpighian Bodies, and of the Tubes emerging from them in Fractions of an English Inch.

	Diameter of Malpighian bodies.			Diameter of tubes.
	Maximum.	Mean.	Minimum.	
Man	$\frac{1}{80}$	$\frac{1}{104}$	$\frac{1}{144}$	$\frac{1}{480}$
Badger	$\frac{1}{104}$	$\frac{1}{124}$	$\frac{1}{150}$	$\frac{1}{416}$
Dog	$\frac{1}{120}$	$\frac{1}{135}$	$\frac{1}{156}$	$\frac{1}{600}$
Lion	$\frac{1}{70}$	$\frac{1}{80}$	$\frac{1}{90}$	$\frac{1}{312}$
Cat	$\frac{1}{156}$	$\frac{1}{200}$	$\frac{1}{250}$	$\frac{1}{680}$
Kitten	$\frac{1}{208}$	$\frac{1}{260}$	$\frac{1}{312}$	$\frac{1}{1000}$
Rat	$\frac{1}{208}$	$\frac{1}{180}$	$\frac{1}{150}$	$\frac{1}{416}$
Mouse (*Mus*)	$\frac{1}{220}$	$\frac{1}{255}$	$\frac{1}{312}$	$\frac{1}{770}$
Squirrel (*Sciurus vulgaris*)	....	$\frac{1}{207}$	....	$\frac{1}{770}$
Rabbit (*Lepus Cuniculus*)	....	$\frac{1}{156}$	....	$\frac{1}{625}$
Guinea Pig (*Cobaya*)	....	$\frac{1}{208}$	....	$\frac{1}{600}$
Horse	$\frac{1}{55}$	$\frac{1}{70}$	$\frac{1}{90}$	$\frac{1}{416}$
Parrot (*Psittacus*)	....	$\frac{1}{430}$	....	$\frac{1}{600}$ to $\frac{1}{700}$
Tortoise (*Testudo*)	....	$\frac{1}{240}$	....	$\frac{1}{480}$
Boa	$\frac{1}{230}$	$\frac{1}{400}$	$\frac{1}{540}$	$\frac{1}{540}$
Frog (*Rana*)	....	$\frac{1}{250}$		
Eel (*Anguilla vulgaris*)	....	$\frac{1}{207}$		

The kidney of the Boa shows very beautifully the reason of the different size of the Malpighian bodies in different parts of the same gland observed in all animals; and also one cause of the striking difference in their size in different animals, and especially in different-sized animals of the same natural group. Its lobes are much thinner at their convex border, opposite the hilus, than elsewhere. The tubes are consequently much shorter there, and I have remarked that the Malpighian tufts are also much smaller. This correspondence between the size of the Malpighian bodies and the length of the tubes, throws much light on the function of the former. A further study of the varieties here displayed in the size of the Malpighian tufts seems highly desirable.

Reflecting on this remarkable structure of the Malpighian bodies, and on their singular connection with the tubes, I was led to speculate on their use. It occurred to me that as the tubes and their plexus of capillaries were probably, for reasons presently to be stated, the parts concerned in the secretion of that portion of the urine to which its characteristic properties are due (the urea, lithic acid, &c.), the Malpighian bodies might be an apparatus destined to separate from the blood the watery portion. This view, on further consideration, appears so consonant with facts, and with analogy, that I shall in a few words state to the Society the reasons that have induced me to adopt it. I am not unaware how obscure are the regions of hypothesis in physiology, and shall be most ready to renounce my opinion, if it be shown to be inconsistent with truth.

In extent of surface, internal structure, and the nature of its vascular network, the membrane of the uriniferous tubes corresponds with that forming the secreting surface of other glands. Hence it seems certain that this membrane is the part specially concerned in eliminating from the blood the peculiar principles found in the urine. To establish this analogy, and the conclusion deduced from it, a few words will suffice. 1. The extent of surface obtained by the involutions of the membrane, will by most be regarded as, itself, sufficient proof. But, 2. Its internal structure is conclusive. Since epithelium has been found by Purkinje and Henle in such enormous quantities on the secreting surface of all true glands, its use cannot be considered doubtful. It never forms less than $\frac{19}{20}$ths of the thickness of the secreting membrane, and in the liver it even seems to compose it entirely, for there I have searched in vain for a basement tissue, like that which supports the epithelium in other glands. As I have endeavoured to show in the forthcoming Number of the Cyclopædia of Anatomy, the epithelium thus chiefly forming the substance of secreting membrane, differs in its general characters from other forms of this structure. Its nucleated particles are never clothed with cilia, and are not surrounded with a definite cell-membrane. They are more bulky, and appear from their refractive properties to contain more substance, their internal texture being very finely mottled, when seen by transmitted light. In these particulars, the epithelium of the kidney-tubes is eminently allied to the best-marked examples of glandular epithelium. 3. The capillary network surrounding the uriniferous tubes is the counterpart of that investing the tubes of the testis, allowance being made for the difference in the capacity of these canals in the two glands. It corresponds with that of all true glands in lying on the deep surface of the secreting membrane, and in its numerous vessels everywhere anastomosing freely with one another.

These several points of identity may seem too obvious to be dwelt upon, but I have detailed them in order to show, that in all these respects, the Malpighian bodies differ from the secreting parts of true glands. 1. The Malpighian bodies comprise but a small part of the inner surface of the kidney, there being but one to each tortuous tube. 2. The epithelium immediately changes its characters, as the tube ex-

pands to embrace the tuft of vessels. From being opake and minutely mottled, it becomes transparent, and assumes a definite outline. From being bald, it becomes covered with cilia (at least in reptiles, and probably in all classes); and, in many cases, it appears to cease entirely, a short way within the neck of the Malpighian capsule. 3. The blood-vessels, instead of being on the deep surface of the membrane, pass through it, and form a tuft on its free surface. Instead of the free anastomosis elsewhere observed, neighbouring tufts never communicate, and even the branchlets of the same tuft remain quite isolated from one another.

Thus the Malpighian bodies are as unlike, as the tubes passing from them are like, the membrane, which, in other glands, secerns its several characteristic products from the blood. To these bodies, therefore, some other and distinct function is with the highest probability to be attributed.

When the Malpighian bodies were considered merely as convoluted vessels without any connection with the uriniferous tubes, no other office could be assigned them, than that of delaying the blood in its course to the capillaries of the tubes, and the object of this it was impossible to ascertain. Now, however, that it is proved that each one is situated at the remotest extremity of a tube, that the tufts of vessels are a distinct system of capillaries inserted into the interior of the tube, surrounded by a capsule, formed by its membrane and closed everywhere except at the orifice of the tube, it is evident that conjectures on their use may be framed with greater plausibility.

The peculiar arrangement of the vessels in the Malpighian tufts is clearly designed to produce a retardation in the flow of the blood through them. And the insertion of the tuft into the extremity of the tube, is a plain indication that this delay is subservient in a direct manner to some part of the secretive process.

It now becomes interesting to inquire, in what respect the secretion of the kidney differs from that of all other glands, that so anomalous an apparatus should be appended to its secerning tubes? The difference seems obviously to lie in the quantity of aqueous particles contained in it; for how peculiar soever to the kidney the proximate principles of the urine may be, they are not more so than those of other glands to the organs which furnish them.

This abundance of water is apparently intended to serve chiefly as a menstruum for the proximate principles and salts which this secretion contains, and which, speaking generally, are far less soluble than those of any other animal product. This is so true, that it is common for healthy urine to deposit some part of its dissolved contents on cooling. It may seem that an exception to this exists in the solid urine of some reptiles; but this expression merely describes the urine as it is found in the cloaca and larger excretory channels. The secretion is brought from the tubules of the gland in a fluid state, and only becomes solid by the re-absorption of its aqueous portion after it has traversed the tortuous canals wherein it was formed, and been placed in a condition to be readily expelled from the system. The subordination of the aqueous part to the purpose of eliminating the more essential elements

of the secretion from the secerning tubules of the gland, is therefore here placed in a clear light.

If this view of the share taken by the water be correct, we must suppose that fluid to be separated either at every point of the secreting surface, along with the proximate principles, as has hitherto been imagined, or else in such a situation that it may at once freely irrigate the whole extent of the secerning membrane. Analogy lends no countenance to the former supposition, while to the latter, the singular position, and all the details of the structure of the Malpighian bodies, give strong credibility.

It would indeed be difficult to conceive a disposition of parts more calculated to favour the escape of water from the blood, than that of the Malpighian body. A large artery breaks up in a very direct manner into a number of minute branches, each of which suddenly opens into an assemblage of vessels of far greater aggregate capacity than itself, and from which there is but one narrow exit. Hence must arise a very abrupt retardation in the velocity of the current of blood. The vessels in which this delay occurs are uncovered by any structure. They lie bare in a cell from which there is but one outlet, the orifice of the tube. This orifice is encircled by cilia, in active motion, directing a current towards the tube. These exquisite organs must not only serve to carry forward the fluid already in the cell, and in which the vascular tuft is bathed, but must tend to remove pressure from the free surface of the vessels, and so to encourage the escape of their more fluid contents. Why is so wonderful an apparatus placed at the extremity of each uriniferous tube, if not to furnish water, to aid in the separation and solution of the urinous products from the epithelium of the tube?

Many recently discovered facts* conspire to prove that secretion is a function very nearly allied to ordinary growth and nutrition; that whereas growth and nutrition comprehend two functions, assimilation of new particles and rejection of old, the old being reconveyed into the blood, so secretion consists in a corresponding assimilation and rejection, and only differs in the old particles being at once thrown off from the system, without re-entering the blood. According to this view, all effete material received into the blood from the old substance of the various organs, must be reassimilated by an organized tissue, specially designed for the purpose, before it can be

* Purkinje, Report of the Meeting of Naturalists at Prague in 1837, Isis, No. 7, 1838. Schwann, Froriep's Notiz. Feb. 1838. Henle, Müller's Archiv. 1838–9. [See also Cyclop. of Anatomy, Art. *Mucous membrane*, the conclusion of which is only just published, although that part of it relating to this theory was written in December last. Mr. Goodsir, since this paper was read, has ably advocated this theory in a communication made to the Royal Society of Edinburgh on the 30th of March, an abstract of which I have just seen in the London and Edinburgh Monthly Journal of Medical Science, May 1842. In the same publication is a report of a paper by the same excellent anatomist, on the structure of the kidney, read at the Med. Chir. Soc. of Edinb. on April the 6th. He describes "a fibro-cellular framework, pervading every part of the gland"—analogous to the capsule of Glisson, and "forming small chambers in the cortical portion, in each of which a single ultimate coil or loop of the uriniferous ducts is lodged." This framework is the structure which I have described (pp. 70–1) as the *matrix*. The convoluted tubes and vessels are all imbedded in it.—*June* 1, 1842.]

eliminated: and all secretions designed for an ulterior use in the œconomy must be assimilated by such a tissue in order to their separation from the blood. This tissue is the epithelium of such surfaces, as, from their external anatomical position, can at once release the secretion, when its elaboration is accomplished. The epidermis of the skin, the epithelium of mucous membranes, and that of true glands, all more or less completely fulfil this purpose; but the first is chiefly designed as a protection, the second partly so, and the third is the only one entirely devoted to what is properly called secretion. Into the examination of this general question, it is impossible that I should now enter, but I shall state some considerations connected with it, that seem to have a bearing on the present subject.

This theory, in its widest sense, supposes the epithelium of secreting surfaces either to pass through constant stages of renovation and decay, or else to remain, during a longer period, as a permanent organic form, assimilating and rejecting, in the mode just described. In many cases the epithelial particles appear to be cast off entire when their growth is complete, and thus to form the secretion; in other instances, they seem to lose their substance by a more gradual process, and to waste or dissolve away on the surface of the membrane, as fresh particles are deposited below; in other examples still, there is reason for believing that they are long a persistent structure. It supposes that the elements of all natural secretions have at one time been a part of an organized form, the epithelial particle; but it leaves it uncertain, whether the secretion, in a complete state, always exists in such particles when alive. It does not determine whether the chemical changes which occur in such particles, issue in the completion of the secreted product, until the period arrives for its being shed from the body. Hence it is beyond the reach of objections founded on the chemical examination of glandular organs *en masse*.

Applying this theory to the kidney, it may be considered highly probable that the epithelium of the uriniferous tubes is continually giving up its effete particles, and undergoing a gradual decay. This view harmonizes in a striking manner with what has been before advanced as to the use of the Malpighian bodies. If the peculiar urinous principles were poured out at once, through the walls of the tubes by the capillaries surrounding them, they must be in a dissolved state from the first, and could need no further aqueous current to carry them off; but if they are deposited in a more or less solid form, as a part of an organized tissue, they will require (being so sparingly soluble) an additional and extraneous source of water, by which, when their formation is complete, they may be taken up and conveyed from the gland. The correspondence before noticed (p. 72) between the size of the Malpighian bodies and the length of the tubes coming from them, is a strong argument in favour of this view.

I stated that the large quantity of water in the urine seemed *chiefly* to serve the purpose of a menstruum. But though this quantity is always large, compared with that in other secretions, it is liable to great variation, according to the state of fulness

of the vascular system, and other circumstances. Hence the kidneys appear to share in the office of regulating the amount of water in the body. How admirably the structure of the Malpighian bodies fits them for thus acting as a self-adjusting valve or sluice to the circulation, I need not explain.

It may possibly be considered by some, that, in the preceding observations on the use of the aqueous element of the urine, and on the nature of secretion in general, I have been endeavouring to illustrate a doubtful hypothesis by speculations more doubtful still, *obscurum per obscurius*. But I rest my view of the function of the Malpighian bodies principally on anatomical grounds, and the other considerations have been introduced in connection with it, rather in consequence of the interest they appear to me to add to it, than because I am fully satisfied of their validity. Undoubtedly both questions are worthy of being separately handled, and require a much wider and more elaborate investigation than seems yet to have been given them. Meanwhile they may in turn receive some elucidation from the researches detailed in this paper. Parallel lines of inquiry into the anatomical varieties of the Malpighian bodies and uriniferous tubes, and into the chemistry of their secretion, in the different tribes of animals and in various stages of their development, could scarcely fail either to confirm or to confute what has now been advanced.

I shall conclude with three remarks founded on the foregoing facts and speculations.

1. The bile and the urine have been ever classed together as the most important excretions. The former is secreted from venous blood; the latter it has been thought from arterial blood, except in some inferior animals, in which the blood from the lower part of the body circulates through the kidneys. But it is a most striking fact, that the proximate principles of the urine, like those of the bile, are secreted *in all animals* from blood which has already passed through one system of capillaries, in a word, from portal blood; although it does not appear to what extent its qualities are changed by traversing the Malpighian system. The analogy is at least remarkable, and may throw some light on the mysterious meaning of the portal circulation.

2. *Diuretic medicines* appear to act specially on the Malpighian bodies; and *various foreign substances*, particularly salts, which, when introduced into the blood, pass off by the urine with great freedom, exude in all probability through this bare system of capillaries. The structure of the Malpighian bodies indicates this, and also, as far as they are known, the laws regulating the transmission of fluids through organized tissues, modified in their affinities by vitality.

3. The escape, also, of certain morbid products, occasionally found in the urine, seems to be from the Malpighian tufts. I allude especially to *sugar, albumen,* and *the red particles of the blood*: the two first of which would transude, while the last would escape only by rupture of the vessels*.

* See Note, p. 67.

3 *Norfolk Street, Strand,*
February 14*th,* 1842.

Explanation of the Plate.

PLATE IV.

Fig. 1. Malpighian tuft—Horse. The injection has penetrated only to the capillaries. *a.* The artery. *af.* One of its terminal twigs (or the afferent vessel of the Malpighian body). *d.* The dilatation and mode of breaking up of the terminal twig, after entering the capsule: the division of the tuft into lobes *l, l, l, l,* is well seen. *i, i.* Intervals between the lobes. Magnified about eighty diameters.

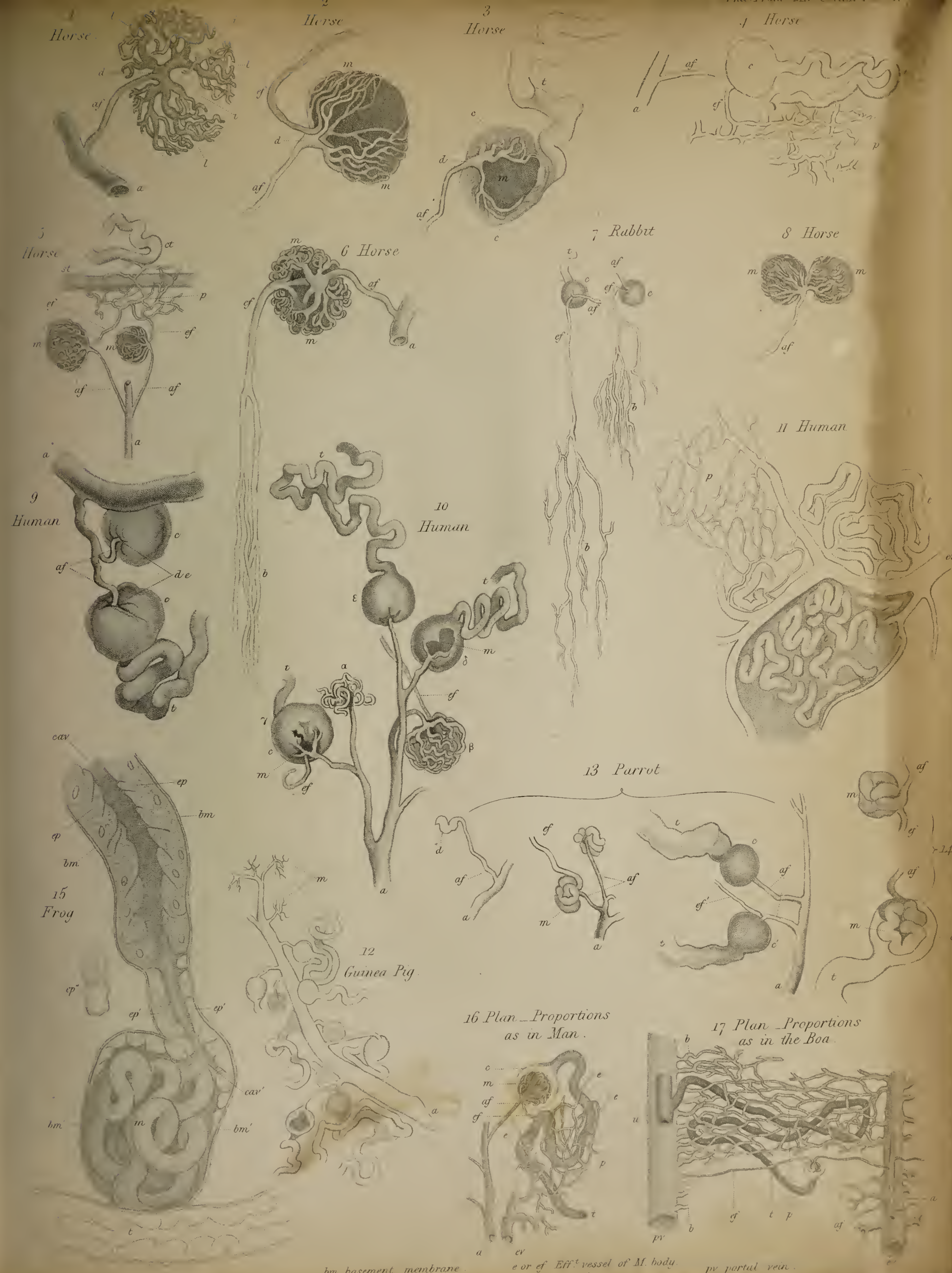
Fig. 2. Malpighian tuft—Horse. The injection has penetrated through the tuft and has filled the efferent vessel, here coloured yellow for distinctness' sake. *af.* The afferent vessel. *d.* Its dilatation and mode of division. *m, m.* Malpighian capillaries. *ef.* Efferent vessel springing from them, and leaving the capsule between two primary branches of the afferent vessel. Magnified about eighty diameters.

Fig. 3. Malpighian body—Horse. The injection, after filling the primary branches of the afferent vessel, has burst into the capsule and passed off along the tube. It has not filled the tuft of capillaries, which consequently are not seen, nor has it spread within the capsule over the whole surface of the tuft. *af.* The afferent vessel. *d.* Its dilatation and mode of subdivision. *c, c.* The outline of the distended capsule. *t.* The tube passing from it. *m.* Situation of the uninjected Malpighian tuft. Magnified about seventy diameters.

Fig. 4. From the Horse. The injection has penetrated from the artery, through the Malpighian tuft, into the plexus surrounding the tubes. It has then ruptured the vessels of the tuft, filled the capsule, and passed off along the tube. *a.* Arterial branch. *af.* Afferent vessel. *c.* Capsule distended. *t.* Tube. *ef.* Efferent vessel. *p.* Plexus of capillaries, surrounding other tubes not injected. Magnified about thirty diameters.

Fig. 5. From the Horse. The injection has passed as in the last-described specimen, but without rupture of the Malpighian tuft. *a.* Branch of the artery. *af, af.* Afferent vessels. *m, m.* Malpighian tufts. *ef, ef.* Efferent vessels. *p.* Plexus surrounding the tubes. *st.* Straight tube in cortical substance. *ct.* Convoluted tube in ditto. Magnified about thirty diameters.

Fig. 6. From the Horse. Malpighian tuft, from near the base of one of the medullary cones, injected without extravasation, and showing the efferent vein branching like an artery, as it runs into the medullary cone. *a.* Arterial branch. *af.* The afferent vessel. *m, m.* The Malpighian tuft. *ef.* The efferent vessel. *b.* Its branches entering the medullary cone. Magnified about seventy diameters.



a arterial branch. bm basement membrane c capsule of M. body. e or ef Eff.t vessel of M. body. ev emulg.t vein. pv portal vein. t tube.

Fig. 7. Similar specimens from the Rabbit, but with extravasation into the capsule, and at *t* into the tube also. *af, af.* Afferent vessel. *c, c.* The capsule. *t.* The tube. *ef, ef.* The efferent vessel. *b, b.* Its branches entering the medullary cone. Magnified about thirty diameters.

Fig. 8. From the Horse. Two Malpighian tufts springing close together from a single terminal twig of the artery. An unusual arrangement. *af.* Afferent vessel. *m, m.* Malpighian tufts. Magnified about thirty diameters.

Fig. 9. From the human subject. Two Malpighian bodies injected. The tufts are burst and the fluid has escaped into the capsule. In one case it has passed also along the tube, the extreme tortuosity of which at its commencement, is well seen. *a.* Arterial branch. *af.* Terminal twigs. *c, c.* Malpighian capsules distended. *de.* The depression often seen in such cases, at the point where the afferent and efferent vessels pass: the latter are not here injected. *t.* The tube. Magnified about ninety diameters.

Fig. 10. From the human subject. This specimen has been chosen because it exhibits the termination of a considerable arterial branch, wholly in Malpighian tufts, and because the several Malpighian bodies injected show different appearances of a very instructive kind. *a.* Arterial branch with its terminal twigs. At α the injection has only partially filled the tuft. At β it has entirely filled it, and has also passed out along the efferent vessel *ef*, without any extravasation. At γ it has burst into the capsule and escaped along the tube *t*, but has also filled the efferent vessel *ef.* At δ and ε it has been extravasated and passed along the tube. At *m* and *m* (as in fig. 3) the injection on escaping into the capsule has not spread over the whole tuft. Magnified about forty-five diameters.

Fig. 11. A minute portion of the *surface* of the human kidney, injected from the *artery*. The injection has burst many Malpighian tufts within the cortical substance, and so filled the tubes, the convolutions of which on the surface of the organ are here displayed. It has also traversed other Malpighian tufts without extravasation, and so filled the capillary plexus surrounding the tubes and some radicles of the vein. *t, t.* Tortuous tubes as seen on the surface: these, with their capillaries, cover the surface, so that no Malpighian bodies appear. *p.* Capillary plexus surrounding the tubes, as seen on the surface. *ev.* A branch of one of the stelliform veins. Magnified about forty-five diameters.

Fig. 12. From the Guinea Pig (*Cobaya*). Terminal branch of the renal artery injected. The injection has burst most of the Malpighian tufts and passed off along the tubes. *a.* Arterial branch. At *m* are seen a few Malpighian tufts partially injected without extravasation. Magnified about forty diameters.

Fig. 13. From the Parrot (*Psittacus*). Injected by the artery. *a, a, a.* Terminal branches of the artery. *af, af, af.* Terminal twigs of the artery. *d.* Dila-

tation of the terminal twig on entering the Malpighian capsule. *m.* This dilatation more completely filled, showing its convoluted form, and *ef.* the efferent vessel. *c.* The Malpighian capsule filled, by extravasation from the contained vessel, and the tube *t* likewise filled. *c'.* The same, with the efferent vessel *ef*, also filled. Magnified about eighty diameters.

Fig. 14. From the Boa Constrictor. Injected by the artery. *af*, *af.* Terminal twigs of the artery. *m*, *m.* The convoluted dilated part within the Malpighian capsule. *ef.* The efferent vessel. *c.* The capsule—visible, but not injected. *t.* The commencement of the tube. Magnified about seventy diameters.

[All the preceding figures are viewed by reflected light.]

Fig. 15. From the Frog; viewed by transmitted light. Shows the continuity of the Malpighian capsule with the tube, the change in the character of the epithelium, and the vascular tuft. *bm*, *bm.* Basement membrane of the tube. *ep*, *ep.* Epithelium of the tube. *cav.* Cavity of the tube. *bm'*, *bm'.* Basement membrane of the capsule. *ep'*, *ep'.* Epithelium of the neck of the tube, and of the neighbouring part of the capsule: this epithelium is covered with cilia, which were seen in active motion eight hours after death. *ep''.* Detached epithelial particle, more highly magnified, showing the relative length of the cilia, as they appeared in this specimen. *cav'.* Cavity of the capsule, in which the capillaries, *m*, lie bare, having entered the capsule near *t*, where the view is obscured by another tube. Magnified about 320 diameters.

Fig. 16. *Plan of the renal circulation in Mammalia.* The relative proportions and the character of the several parts are accurately copied from preparations of the *Human* kidney. The artery *a*, (coloured pink) is seen giving a terminal twig *af*, to a Malpighian tuft, *m*, from which emerges the efferent (or portal) vessel *ef* (coloured yellow). Other efferent vessels are seen, *e*, *e*, *e*. All these enter the plexus of capillaries *p* (coloured blue) surrounding the uriniferous tube *t* (coloured red). From this plexus the emulgent vein *e v* springs. Supposed to be magnified about forty diameters.

Fig. 17. *Plan of the renal circulation in animals furnished with a portal vein from an extraneous source.* The colours correspond with those of fig. 16. The relative proportions and position are copied from the kidney of the *Boa* (p. 64), of which a vertical section of one half of a lobe is supposed to be made. *a.* Artery. *af.* Terminal twig going to the Malpighian body. *ef.* Efferent vessel of the Malpighian body emptying itself into a branch of the portal vein *p v* on the surface of the lobe. *b*, *b.* Ultimate branches of the portal vein, entering the capillary plexus *p*, surrounding the uriniferous tube *t*. *u.* Branch of the ureter on the surface of the lobe. *ev.* Emulgent vein within the lobe, receiving the blood from the plexus surrounding the uriniferous tubes. Supposed to be magnified about forty diameters.

V. *On the Chemical Analysis of the Contents of the Thoracic Duct in the Human Subject.* *By* G. Owen Rees, *M.D., F.G.S., Physician to the Northern Dispensary. Communicated by* P. M. Roget, *M.D., Sec. R.S., &c.*

Received February 3,—Read February 10, 1842.

THE contents of the thoracic duct in the human subject having never been obtained in sufficient quantity for the purposes of chemical analysis, I resolved to avail myself of an opportunity which lately presented itself in the execution of a criminal at the Old Bailey.

Through the kindness of Messrs. Macmurdo and Holding, the medical officers of Newgate, and with the assistance of my friends Mr. Hilton and Mr. Samuel Lane, I was enabled to commence operating upon the body one hour and a quarter after death, and before it had become cold, although the thermometer stood considerably below 32° Fahr., and the body had been exposed on the scaffold during one hour. The subject was muscular and of the middle height, and the prisoner had not become emaciated during his confinement in jail. On the evening preceding his execution, he had partaken of some supper, consisting of about 2 oz. of bread and 4 oz. of meat; and the next morning, he drank two cups of tea, and ate a piece of toast made from the quarter of a round of a quartern loaf, and about a quarter of an inch in thickness. This breakfast was taken at seven o'clock A.M., one hour before death. He swallowed a glass of wine just before mounting the scaffold.

The contents of the posterior mediastinum having been previously included in a ligature from the left side, the thoracic duct was reached without much difficulty by raising the right lung, and dividing the pleura which forms the right boundary of the posterior mediastinum. The duct was easily found, being distended with chyle: it was seized immediately below the point at which it was intended to divide it. The operator detached it as much as possible from its cellular connexions, and holding it between the thumb and finger, it was divided while thus compressed. The fingers and lower part of the duct were then well washed by pouring clean water over them in order to be certain that no serous secretion or blood might become mixed with the chyle. The divided extremity of the duct was next placed in a perfectly clean glass bottle, into which its liquor flowed freely; its motion being facilitated by gently kneading the abdominal contents. In this manner nearly six fluid drachms of chyle were obtained, the physical characters of which were as follows:—It was of a milky hue, with a slight tinge of buff. Its consistence was much the same as that of milk. The latter portion which was obtained (four drachms being received in a first, and

two drachms in a second bottle) coagulated on becoming cold; but the portion received in the first bottle being retained in the hand of Mr. Holding, and thus kept at a higher temperature, did not coagulate during a full hour; and on subsequently being allowed to cool to the same extent as the specimen obtained in the other bottle, it still remained perfectly fluid. The coagulation which took place in the other specimen was however very slight; and a partial resolution of the clot occurred after a few hours had elapsed*. The specific gravity of this fluid was 1·024. Chemical examination yielded the following results.

When fresh, it was neutral in its reaction on test papers; a portion, however, which was kept some days, became slightly acid during decomposition.

The application of heat coagulated it strongly. The addition of nitric acid also produced a strong curd.

Acetic acid did not coagulate it, but, on the contrary, rendered it somewhat more pellucid. The addition of acetic acid and the subsequent addition of a solution of ferrocyanuret of potassium produced a strong white flocculent precipitate. A portion of the fluid was next submitted to analysis in the following manner.

The proportion of water was ascertained by careful evaporation over a water-bath until no decrease of weight was observed by further application of heat; the loss indicated the weight of the water. The solid extract obtained was finely powdered, digested with ether for a day in a closed vessel, and then again similarly treated with a second portion of the menstruum; lastly it was washed with ether. The ethereal solutions thus obtained were mixed together and evaporated; the solid residue was estimated as fatty matter. The portion insoluble in ether was next treated with boiling distilled water, and allowed to digest at a temperature of about 57° Fahr. for twelve hours. It was then again similarly treated, care being taken to pour off the first digested portion of water as nearly as possible without disturbing the deposit, before adding the second quantity. The solid matter was then placed on a filter washed with distilled water, dried and weighed as albumen. The filtered liquors and washings were collected and evaporated together, and the dry result treated with successive portions of alcohol, of the specific gravity 0·832, until everything soluble in that menstruum was dissolved out. The insoluble portion was then dried and weighed as "animal extractive matter and salts soluble in water only;" and the alcoholic solutions being evaporated, their extract was estimated as "animal extractive matter soluble in water and alcohol." The salts were obtained from these extractives by incineration and carefully conducted decarbonization; and their weights being subtracted from that of their respective extractives, the difference gave the true weight of the animal extractive matter with which they had been combined. The quantitative analysis, conducted as above, yielded the following result in 100 parts:—

* The fibrin of the lymph and chyle of the Ass coagulate with sufficient strength to admit of separation and estimation in analysis.

Water	90·48
Albumen with traces of fibrinous matter	7·08
Aqueous extractive	0·56
Alcoholic extractive, or Osmazome	0·52
Alkaline chloride, carbonate, and sulphate, with traces of alkaline phosphate and oxide of iron	0·44
Fatty matters	0·92

The fatty matters extracted in this analysis possessed, for the most part, the same characters as those of the blood, being separable by boiling in alcohol, and subsequent cooling, into a crystalline fat, which was deposited as the alcohol became cool, and an oily matter which was completely soluble in cold alcohol; these fats differed, however, from those of the blood in not containing phosphorus, which was proved by their yielding an alkaline, instead of an acid ash on incineration. The albuminous matter was not of the dead white colour observed in that obtained from pure chyle, owing, doubtless, to the contents of the thoracic duct containing a considerable proportion of lymph. On incinerating this albumen, an ash was obtained, containing phosphate of lime and traces of oxide of iron. The whole of the spontaneously coagulable albumen or fibrin*, which presented itself as clot in part of this chyle, is estimated as albuminous matter in this analysis, as it was found quite impossible to separate it without considerable loss, and the coagulum was very slight and broke down very rapidly.

The aqueous and alcoholic extractives mentioned in this analysis agreed in most respects in chemical characters with those obtained from the blood, with the exception that the aqueous extractive yielded a ferruginous ash, which is never the case with that principle as procured from the blood. I have ascertained by experiment that pure chyle obtained from the lacteals of the Ass yields an aqueous extractive containing iron; it is, therefore, to the chyle and not to the lymph that we owe this property of the aqueous extractive. The salts, obtained by incineration from the alcoholic extractive, yielded a larger proportion of alkaline carbonate than is obtained from the blood, indicating a larger proportion of an alkaline lactate in the contents of the thoracic duct. I have alluded to the dead white colour of the albuminous matter obtained from pure chyle, and stated that the admixture of lymph in the contents of the thoracic duct interfered with its developement in the albumen obtained from the fluid the examination of which I have detailed. Some months ago I had an opportunity of tracing this effect to its true cause, namely the presence, in the chyle, of an opake white organic matter identical with a substance existing as a constituent of the saliva, and which appears to act an important part in the process of nutrition. I have obtained this animal substance on a former occasion in consider-

* I have thought it right to apply to fibrin the term spontaneously coagulable albumen, the recent observations of Liebig and others having shown it to be chemically identical with albumen.

able quantity from the chyle of the Ass, and found it to exhibit peculiar characters, which I have described in the Medical Gazette for January 1, 1841, to which I may refer also for a comparative analysis of the chyle and lymph of this vegetable feeder. It has frequently been stated by observers, that chyle, when set aside to coagulate, assumes a pink colour if exposed to the air; this is stated to be the case by MÜLLER in the chyle from the thoracic duct of the Horse. My own observations do not agree with this statement; for fluid taken from the thoracic duct of the Dog, Ass, and Cat, as also that lately obtained from the human subject, showed no such change of colour when under the conditions mentioned by MÜLLER. There were, indeed, a few blood-corpuscles to be seen by microscopic examination; but these were so few in number and so divided as not to manifest their colour, and were, I have no doubt, taken up by the divided mouths of some of the absorbents which emptied themselves into the thoracic duct during the period occupied by us in obtaining its contents. Mr. SAMUEL LANE was, I believe, the first observer who traced the existence of the blood-corpuscle in the chyle to its true cause, and showed that chyle might be procured free from such contamination, if the contents of the thoracic duct were speedily obtained. I have had occasion in this analysis to verify my former views concerning the cause of the white colour of the chyle, which I feel confident is chiefly attributable to its containing the opake white salivary matter as a constituent. This substance is always, however, mixed with a certain proportion of fatty matter. It may be obtained from chyle by agitation with ether; when we find it to subside through the ether, and to float on the surface of the chyle which has now become cleared.

The microscopic examination of human chyle has been much neglected. From the appearances observed in the specimen lately obtained, I am enabled to state that its corpuscles are of the same description as those in the chyle of purely animal and vegetable feeders. They consist of two classes, viz.—1. Larger spheroidal bodies, varying in size, but for the most part larger than the blood-corpuscles, semitransparent, and granular on the surface. The largest of these corpuscles are nearly twice the diameter of those of the blood. 2. Minute granules varying in size from about $\frac{1}{16}$th the diameter of the blood-corpuscle to a size which scarcely admits of their being seen, except by the aid of a perfect light and a microscope capable of magnifying to about 750 diameters, when they appear to form a kind of back-ground on which are seen the larger corpuscles first noticed. These granules have been described by Messrs. LANE and GULLIVER as existing in the chyle of animals. Mr. LANE has likewise described a molecular motion in them, which I have had occasion to verify. Besides these corpuscles and granules we also detect fatty globules in the chyle, varying greatly in size. If we compare the analysis I have given of the contents of the thoracic duct with the analysis of the blood, we cannot fail to be struck with the very great excess of fatty matter existing in the former. We have a large quantity of an hydrocarbonous ingredient constantly entering the blood, and becoming consumed with great rapidity, as proved by the small percentage

of fatty matter contained in the mass of blood. Whether this hydrocarbonous matter is exhaled by the lungs and skin in the form of water and carbonic acid, or whether, on the contrary, an absorption of nitrogen and oxygen occurs in the process of respiration, so as to convert the fat of the chyle into albuminous matters for the purposes of secretion and nutrition, is not yet determined; many circumstances, however, seem to favour the latter view; thus, the chyle of an animal fed on beans and oats, substances very different in quality from fatty matters, is found to contain a very large proportion of fat, destined, no doubt, for some useful purpose of the animal economy, and which would scarcely be produced from aliment in order to be subjected to a direct process of excretion. The proportion of "extractive matter soluble in water and alcohol" or osmazome, will be found greatly to exceed the amount of that principle contained in the blood; agreeing well with what we know concerning the universal distribution of this substance as a constituent of the soft parts of the human frame.

VI. *Report of a remarkable appearance of the Aurora Borealis below the Clouds. By the Rev.* JAMES FARQUHARSON, *LL.D., F.R.S., Minister of the Parish of Alford.*

Received March 17,—Read April 14, 1842.

ALFORD, February 24, 1842.—Saw, at 11 P.M., a remarkable aurora borealis, between the observer and lofty stratus clouds. The density of the clouds, the great brilliancy of the meteor, its considerable continuance, its renewed display, and the extent of space it occupied, left no doubt of the reality of the phenomenon.

After a day, during which the whole heavens had been mostly shrouded by a uniform cloud, with a gentle wind at N.W., the sky, after sunset, became partially clear; and the thermometer descended to 34°, with calm. Barometer 28·89 inches. At 11 P.M. a very brilliant display of pencils of aurora (streamers) was seen at W. by S., in a limited space about 10° broad, and 15° or 20° high, a little above the visible horizon; and a separated display of the same, much wider, and of nearly the same height, but not quite so brilliant, in another limited space at N.W. It was instantly seen that in both spaces the bright meteor was between the eye and lofty stratus clouds. These clouds extended in long parallel belts, some of them 10° or 15° broad, some broader, with narrow intervals of clear sky between them, in a direction from N.W. to S.E. This arrangement was clearly seen in all the western part of the sky, although there existed under these clouds thinner fleecy irregular ones, which here and there obscured it for short distances. These lower irregular clouds prevailed more in the eastern part of the sky; but there, also, the arrangement of the belts of stratus was recognised through their intervals. One of the irregular thin clouds lay over the moon, then nearly south, and nearly at full; and its consistency was such as to obscure the dark spaces on her disc, although not its circular outline. The lofty stratus clouds, were, in some parts at least, of much denser consistency; as was proved by their totally obscuring some very brilliant falling stars, which passed behind them, as will be afterwards described.

The exhibition of pencils of aurora at the W. by S. space was of unusual brilliancy, and the coruscations incessant, as they brightened up, and faded, and suddenly disappeared, and were renewed, successively. The colour at the lower extremity was a lively minium red, but only for a short way up; the upper part being of the common greenish yellow. They crossed, angularly, the lofty cloud nearest to the western horizon, which was narrow, and were clearly seen upon its face, and stretching their extremities into the clear sky on each side of it. Even the feeblest of them maintained its continuity and its peculiar tinge of colour, over both the thinner

edges, and denser middle part of the stratus. About five minutes after it was first seen, this aurora became extinct; but in the course of three or four minutes was suddenly renewed, with a slight shift to the southward, in as great or even greater brilliancy. In the mean time, the aurora at the N.W. space exhibited like appearances, and colours; red at the lower extremities of the brilliant pencils, and greenish yellow upwards. The space here occupied by the pencils, or streamers, was much broader, and the lights less condensed into one place, disappearing in some compartments and extending to others alternately. They played over several belts of the stratus clouds, and intervening clear spaces of sky; and were seen, without diminution of lustre or change of tinge, on the face of the former. At both sides of this space, there were some of the thin irregular lower clouds, behind which some of the pencils passed, sometimes at one or other of their extremities, sometimes at their middle part. In such cases their continuity instantly disappeared; for although the light of the more brilliant ones shone through these clouds, it was only in a white nebulous form, without any parallelism of rays, as seen in the pencils when not so obscured.

About twenty minutes after the aurora was first seen, dense clouds with curled edges were rather quickly formed over both the spaces occupied by it, of larger extent than they were; and although the observations were continued till half-past twelve o'clock, the meteor was not again seen in the same spaces; but about a quarter to twelve o'clock, a comparatively small space of bright nebulous aurora, without defined pencils, was seen very near the horizon at W.N.W. That too disappeared; and in the mean time the clouds in all parts of the sky by degrees dissolved; the lofty stratus ones more slowly than the others. At half-past twelve o'clock, only a few remained at the S.E., when the observations were discontinued.

During the continuance of the aurora, two bright shooting stars descended above the space at N.W., in paths parallel to the streamers, that is to the dipping-needle. They were of slow motion, and became invisible when passing over the belts of stratus clouds, but emerged again after passing them. At a quarter to twelve o'clock, a shooting star, as large as Venus at her greatest elongation, shot from near the zenith a little to the eastward of the magnetic meridian, and descended in a path parallel to that circle, disappearing while passing behind some stratus clouds, but not quite while doing so behind some low irregular ones, that lay in its course. Its motion was slow, and fitfully interrupted.

February 25th.—Clear sky in the morning. Unusually abundant spiculæ of hoar frost over all the ground, and whitening the hills to their summits, like a shower of snow. Register thermometer through the night at 29°.

VII. *On Fibre.* *By* Martin Barry, *M.D., F.R.SS. L. and E.*

Received December 3,—Read December 16, 1841.

THERE is scarcely any term so generally used in the description of animal or vegetable tissue, as the term *fibre*. If this serves to show the universal presence of fibre, it also indicates the importance of having a correct notion of its structure. On this subject, however, physiologists differ widely: some believing fibre to be composed of globules, while others maintain that no globules can be discerned in it.

My investigations have led me to adopt neither of these views. Should the observations that I have to communicate be found deserving of attention, it will be owing to my having carefully examined the structure of fibre in the course of its formation, beginning with the very earliest stage. At this period, I had to deal with an object of considerable size; the form of which, therefore, could be distinctly seen: and by tracing the metamorphoses of the large and parent fibre, I was enabled to see in the minute succeeding ones a structure, which I think would not otherwise have been discerned. We may hereafter see the cause of the difference in opinion regarding the structure of fibre.

The present memoir, though devoted to the investigation of fibre, is in fact a continuation of those which I have already communicated to the Society on the Corpuscles of the Blood†.

Formation of a Flat Filament within the Blood-corpuscle.—Structure of this Filament.—Presence of a Filament having the same appearance in the Coagulum of Blood; as well as in the Tissues generally, of both Animals and Plants.—This Flat Filament is what is usually termed a "Fibre."

1. In the mature blood-corpuscle (red blood-disc), there is often to be seen a flat filament or band already formed within the corpuscle. In Mammalia, including Man (Plate V. figs. 4, 1, 2), this filament is frequently annular; sometimes the ring is divided at a certain part; and sometimes one extremity overlaps the other. In Birds (fig. 5.), Amphibia (figs. 8, 9, 10, 11), and Fishes (figs. 12, 13), the filament is of such length as to be coiled.

2. This filament is formed of the discs contained within the blood-corpuscle. In Mammals, the discs entering into its formation are so few as to form a single ring; whence the biconcave form of the corpuscle in this class, and the often annular form

† Part I. Philosophical Transactions, 1840, p. 595, Part II. Philosophical Transactions, 1841, p. 201, Part III. Philosophical Transactions, 1841, p. 217.

of the filament it produces. In the other Vertebrata, the discs contained within the blood-corpuscle are too numerous† for such a ring; therefore their arrangement forms a coil. At the outer part of this coil, the filament (already stated to be flat) is often on its edge (figs. 10, 11, 12), from which arises a greater thickness of the corpuscle, and the appearance it has of being cut off abruptly at this part; while in the centre, there is generally the unappropriated portion of a nucleus (figs. 8, 10): whence the central eminence, around which there appears a depression in those corpuscles that, from the above cause, have the edge thickened.

3. The nucleus of the blood-corpuscle in some instances resembles a ball of twine, being actually composed, at its outer part, of a coiled filament (fig. 10 β, γ).

4. Such of the Invertebrata as I have examined (figs. 14, 15), likewise present the blood-corpuscle passing into a coil.

5. Acetic acid dissolves the part most advanced, leaving the newest part behind. This accounts for the figures accompanying my Part II. on the Corpuscles of the Blood‡, representing corpuscles of Birds, Amphibia, and Fishes, from which the filament in question, or its elements, had been removed by this reagent.

6. The filament thus formed within the blood-corpuscle, has a structure which is very remarkable (see the figures just referred to). It is not only flat, but deeply grooved on both surfaces; being thereby thinner in the middle than at the edges. The edges are rounded: and when seen on its edge, the filament at first sight seems to consist of segments. It is important, however, to observe, that the line separating the apparent segments from one another, is not directly transverse, but oblique (see fig. 9 γ).

7. Of course the structure of an object so minute, cannot be seen without a very high magnifying power, and a good light. And it may be here remarked, that in the researches forming the subject of this paper, I have generally added dilute spirit (sp. gr. about 0·940), containing about $\frac{1}{200}$th of corrosive sublimate§.

8. It is deserving of notice,—in the first place, that portions of the coagulum of blood sometimes consist of filaments having a structure identical with that of the filament formed within the blood-corpuscle; secondly, that, in the coagulum, I have noticed the ring formed in the blood-corpuscle of Man (fig. 4), and the coil formed in that of Birds (fig. 6) and Reptiles, unwinding themselves into the straight and often parallel filaments of the coagulum,—changes which may be also seen taking place in blood placed under the microscope before its coagulation; thirdly, that I have noticed similar coils strewn through the field of view (figs. 7, 17), when examining various tissues,—the coils here also appearing to be altered blood-corpuscles, and

† Philosophical Transactions, 1841, Pl. XVIII. figs. 52 γ, 54 ϵ. In all vertebrated animals the *young* blood-corpuscle is a mere disc, with a depression in the centre. In Mammalia it continues of this form; while in the other Vertebrata it becomes a nucleated cell. ‡ *L. c.*, Pl. XVIII.

§ For the examination of certain tissues, especially muscle, I have since used chromic acid—sp. gr. about 1·050.

unwinding; lastly, that filaments having the same structure as the foregoing, are to be met with apparently in every tissue of the body.

9. I proceed to enumerate the parts in which I have observed the same kind of filaments; without stopping to point out peculiarities in their size or in their mode of combination in the various parts. Future observers will find, that while in some parts they have coalesced to produce a membrane, have themselves passed into tubes, or are otherwise rendered indistinct, they retain their form remarkably, being sometimes crossed in various directions, or at other times lying parallel. Some remarks on this subject will be found in the explanation of the figures, as for instance in that of the cornea (fig. 91). The parts in which I have noticed the filaments in question are these: the cortical and medullary substance of both the cerebrum and cerebellum, the spinal chord, the optic nerve and retina, the olfactory and auditory nerves, nerves connected with the spinal chord, voluntary and involuntary muscle, (the latter including the muscle in all parts of the alimentary canal, and the Fallopian tube and uterus, as well as blood-vessels, the iris and the heart), tendon, elastic tissue, cellular and fatty tissue, serous membranes (peritoneum, pericardium, and arachnoid membrane), various parts of the so-called mucous membrane†, the lining membrane of the large blood-vessels and the valve of a large vein, the skin, the dura mater and the sheath of the spinal chord, ligament, the gums and palate, the stroma of the ovary, the testis and the walls of the vas deferens, the kidney and ureter, the glans, as well as the corpus spongiosum and corpus cavernosum penis, the coats of the gall-bladder and of the cystic duct, the pancreas, the liver. I found them along with the marrow from a bone; between the rings of the trachea, as well as in the substance of the lungs, and the gills of the common Mussel; in the parenchyma of the spleen, the lachrymal gland, the sclerotic coat of the eye, the conjunctiva, the cornea, the membrane of the vitreous humour, the capsule of the crystalline lens, the lens itself, the cartilage of the ear and cartilage of bone, bone itself, the periosteum, the claw of the Bird, the shell-membrane of the egg, substance connecting the ova of the Crab, silk, hair, the incipient feather, the feather-like objects from the wing of the Butterfly and Gnat, and the Spider's web. These are the principal of the animal structures in which I have found filaments such as those above described.

10. Of plants, I subjected to microscopic examination the root, stem, leaf-stalk and leaf, besides the several parts of the flower: and in no instance where a fibrous tissue existed, did I fail to find filaments of the same kind. This was in the Phanerogamia. On subsequently examining portions indiscriminately taken from Ferns, Mosses, Fungi, Lichens, and several of the marine Algæ, I met with an equally general distribution of the same kind of filaments.

11. The flat filament seen by me in all these structures, of both animals and

† I saw a curious interlacement of these filaments on the villi of the lining membrane of the rectum in the Rabbit.

plants, is that usually denominated a "fibre." And the appearance of the filament in all the structures mentioned, was essentially such as that delineated in the figures above referred to: an appearance which I have never before seen represented as that of "fibre."

12. Most of the figures which accompany the memoir present filaments, having the appearance in question. It will be seen to be precisely such as that of the filament formed within the corpuscle of the blood. We know that discoid corpuscles circulate in plants; and it remains to be seen whether filaments are not formed in these.

The foregoing facts, I think, indicate the necessity in physiological research, of not resting satisfied with mere opinion, though emanating from so high an authority as HUNTER; who supposed the corpuscles to be "the least important portion of the blood."

Structure of the Flat Filament ("Fibre") more particularly investigated.

13. We have hitherto viewed the object called by me a flat filament, only in some of its minutest forms. These are sufficient to show that it is a compound structure. But in order to become more particularly acquainted with this structure, it is requisite to trace the filament into similar objects of larger size. For this purpose, it will be sufficient to examine *successively* the following figures, from nervous substance, from muscle, and from the crystalline lens: namely, figs. 117 β, 116 β, 115 β, 114 β, 62, 53, 92, 56, 54, 84, 131.

14. I have attempted in fig. 55. to represent what has appeared to me to be the structure of the objects in the figures now referred to. Here (in fig. 55) we find two spirals, running in opposite directions, and interlacing at a certain point (α), in every wind. This arrangement gives to the entire object a grooved appearance and a flattened form. It is in fact the structure which, for want of a better term, I have called a flat filament. The edge of this filament (figs. 114 β, 56 γ, 62) presents what at first sight seem like segments, but which in reality are the consecutive curves of a spiral thread. A transverse section of such an object is rudely represented by the figure 8. This is precisely the appearance presented also by the minutest filament or "fibre:" and I particularly refer to the oblique direction of the line separating the apparent segments in the smaller filament (fig. 9 γ), in connection with the oblique direction of the spaces between the curves of the spiral threads in the larger one.

15. In further proof of identity in the structure of the larger and the smaller filaments, it may be mentioned that I have seen filaments of minute size to enlarge, and give origin in their interior to other filaments (fig. 131).

16. We shall hereafter find that there is a tendency in these filaments to become membranous at the surface (par. 62). Hence it appears to be, that, very often when the flattened form of the filament and its grooved middle part are distinctly visible, no trace whatever of a crenate edge can be discerned. This may serve to show the necessity for extended observation, before investigators come to a conclusion as to

the existence of filaments, such as those I have described. And here they should be apprized, that the filaments are sometimes exceedingly minute. Such was their condition, for instance, in tendon. In bone also, from which the phosphate of lime had been removed (by muriatic acid), I found them exceedingly minute. The varying appearance of the edges of the filament, just referred to, may assist to explain why some have believed "fibre" to consist of globules; while others have maintained that no globules can be discerned in it.

The Spiral Form as general in Animals as in Plants—Universality—and Early Appearance of the Spiral Form.

17. It is known that vegetable tissue presents, in some parts, a feature which has heretofore seemed wanting, or nearly so, in that of animals—the *spiral* form. I venture to believe that some appearances met with in my investigations may go far towards supplying this deficiency. These appearances will be found represented in the nervous tissue (Plates VI., VIII., IX.), in muscle (Plates VI., VII., VIII., IX.), in minute blood-vessels (fig. 16), and in the crystalline lens (fig. 131). If indeed the view above mentioned—that the larger and the smaller filaments have the same structure—be correct, it follows that spirals are much more general in plants themselves than has been hitherto supposed. Spirals would thus appear, in fact, to be as universal as a "fibrous" structure.

18. The tendency to the spiral form manifests itself very early. Of this the most important instance is afforded by the corpuscle of the blood, as above described. I have also obtained an interesting proof of it in cartilage from the ear of a rabbit (figs. 133 to 136), where the nucleus, lying loose in its cell, resembled a ball of twine; being actually composed, at its outer part, like the nuclei of certain blood-corpuscles, of a coiled filament; which it was giving off to weave the cell-wall; this cell-wall being no other than the last formed portion of what is termed the intercellular substance—the essential part of cartilage.

19. I think there is ground for believing, that the nucleus of the cell in cartilage, now compared to a ball of twine, is descended by fissiparous generation from the nucleus of the blood-corpuscle; which on a former occasion† we saw to give the first origin to cartilage, for I have never seen the nucleus of a cell arise, except as part of a previously existing nucleus‡. It is therefore interesting now to find in each the appearance which I have compared to a ball of twine: though it is not likely that cartilage is the only tissue to which the blood-corpuscle transmits the property in question.

Mode of Origin of the Flat Filament ("Fibre")—Its Reproduction.

20. It is known that, in order to the formation of certain fibrous tissues, cells

† Philosophical Transactions, 1841, Pl. XXII. figs. $116\frac{1}{2}$—122.

‡ Some of the nuclei in the cells of cartilage in figs. 134, 135, were apparently undergoing division.

apply themselves to one another (fig. 28), so as to present the appearance of a necklace; and that subsequently, as the partitions between the cell-cavities are absorbed, this necklace becomes a tube. It is supposed that the ultimate threads of the tissue arise within this tube. But on the subject of the particular mode of origin of these ultimate threads, I am not aware that we possess any published information, except that furnished by Schwann and Valentin: the former having shown that a "secondary deposit" makes its appearance on the inner surface of the wall of the tube†, and the latter, that this deposit soon presents longitudinal threads; which threads have sometimes the appearance of being "composed of longitudinal rows of globules‡." I do not find that any mention has hitherto been made of a *second* order of tubes, arising within the first or parent tube (par. 42). The results obtained by myself are by no means complete; but may perhaps afford information that will serve as a guide in future investigations.

21. Cells applied to one another in the above necklace-like manner, I formerly showed to become filled with discs§. If now fig. 26 γ be referred to, such discs—or cells into which the discs have passed—will be seen arranged in lines, corresponding with the direction of the forming tube. This figure was taken from the mould of cheese. Fig. 36 presents an arrangement of the same kind, noticed in voluntary muscle.

22. One of the purposes for which this linear direction occurs, seems to be the production of smaller tubes within the larger one (fig. 30); and another purpose is apparently a peculiar arrangement of discs within the smaller tube. Such an arrangement is seen in figs. 45 to 48. In some of these, the discs had become rings. The structure of these rings was such as to leave no doubt with me, that the same process was in operation as that producing the changes, above described, in corpuscles of the blood. The blood-corpuscle (fig. 17 α) passes from a mere disc into a ring (β, γ), and this ring into a coil (δ, ε, ε). Now, with the regular arrangement of rings seen at α fig. 48, and with the analogy of the blood-corpuscles just mentioned, it seems highly probable that every ring (fig. 48 α) becomes a coil, and that the extremities of coils in the same line unite, to form a spiral. I have to add, that a spiral (γ) actually existed in this tube (fig. 48) in a line with the rings represented in the figure, having obviously been formed out of such rings: and I know of no way in which the transformation could have been effected so easily and so naturally as that now described.

23. The tube in question (fig. 48) presents, not merely one, but *two* spirals: and these two spirals interlace with one another. This interlacement seems to explain

† Schwann, "Mikroskopische Untersuchungen über die Uebereinstimmung in der Struktur und dem Wachsthum der Thiere und Pflanzen." Tab. IV. fig. 3.

‡ Valentin, in Müller's Archiv, 1840, p. 204. My observations are entirely different from those of Valentin as to the office performed by the nucleus of the cell.

§ "On the Corpuscles of the Blood," Part III., *l. c.*, par. 161.

the remarkable arrangement of the two lines of rings at α. For, during the transition (as I suppose) of the rings into coils, an interlacement is almost a necessary consequence of the alternate succession of the rings. I have also seen this interlacement of spirals provided for, apparently, by the rings of several lines being linked together while still rings (fig. 47: see also fig. 120).

24. Figure 48, from its exhibiting only one side of the tube, represents but two rows of rings. The number of rows, however, contained in the tube seemed four: which of course would become connected in the above way, as easily as two; and give origin to a corresponding number of interlacing spirals.

25. I cannot suppose that minuteness is any hindrance to the smallest filament ("fibre") having its origin *by the same mode*: *and to this, the linear arrangement of the discs within the blood-corpuscle seems to have especial reference*†. Facts will be hereafter mentioned, which seem to show a *fasciculus* of filaments to be thus produced in a certain tissue (par. 42—44).

26. Within the windings of the spirals (fig. 57 α), nuclei are sometimes to be discerned. It appears to be from these nuclei that there proceeds the substance for forming new filaments (fig. 22); which are very often seen within the winds of spirals (figs. 131 β, 94, 58).

27. I have in some instances observed the filaments, when enlarging, to present a remarkable change in the relative position of their spiral threads. If figs. 40, 41 be referred to, it will be seen that α of fig. 40 passes into α of fig. 41, and the latter into β of the same figure. The scheme fig. 60 may illustrate this transition. This scheme is merely an altered state of that in fig. 55. In each there are two spirals; the difference consisting in the relative position of the spirals. The points in contact at α fig. 55, have separated in fig. 60 (α, α); so that now, a transverse section is no longer represented by the figure 8 (par. 14), but by a circle. This latter (fig. 60) seems to exhibit the relative position of the spirals, in some instances, when they begin to form, as will be hereafter shown, the membrane of a tube. Such appears to be their state in fig. 41. β: a state which apparently precedes the formation of the tubes in figs. 42, 43, and the subsequent figures in this Plate.

Facts observed in the Formation and Structure of Nerve.

28. It is known that in the so-called "primitive fibres" into which a nerve can be separated by means of needles, Remak demonstrated a "band-like axis‡," corresponding to the "cylindrical axis of Purkinje‡;" and that the substance surrounding this axis, has been termed by Schwann, the "white substance of the nervous fibre‡." This "white substance" I find to consist of filaments (fig. 112 α, β—fig.

† See my Part III. on the Corpuscles of the Blood, Philosophical Transactions, 1841, Plate XVIII. figs. 52 γ, 54 ε.

‡ Müller's Elements of Physiology, translated by Dr. Baly, Part VI. p. 1649.

102 α, β, γ), having the same structure as those constantly referred to in the present memoir. These filaments, forming the white substance of the nervous fibre, are often seen to be curiously interlaced (fig. 102 γ), as though each filament had a spiral form. In other instances their direction is more longitudinal (fig. 112 α).

29. Professor MÜLLER justly says, "The great size of the so-named primitive fibres of the nerves, as compared with the minute elementary parts of muscles, the cellular and other tissues, excites a doubt as to whether the fibre contained in the nervous cylinder is really its most minute element†." He states that "in fibres of the thickness of the ordinary primitive fibres, which SCHWANN examined in the mesentery of the Frog, he saw other much finer filaments which issued from the larger fibre‡." To the filaments seen by SCHWANN, I shall refer in a future page. MÜLLER adds, that "TREVIRANUS observed in several nervous cylinders streaks running longitudinally, and he even saw distinctly more minute elementary filaments in the so-called primitive cylinders§."

30. The filaments noticed by TREVIRANUS, I think may have been the flat filaments in question. But these flat filaments, as we have seen, have themselves a compound structure.

31. It is very common to find the nerve-cylinder ("primitive fibre") drawn out to a point from manipulation, like the fasciculus of muscle. See remarks on the alteration of the spirals in the muscular fasciculus, and on the office performed by the investing membrane, in this change (par. 54).

32. The filaments in fasciculi from the optic (fig. 107), olfactory (fig. 108), and auditory nerves, have appeared less tense than those in the common spinal nerves; and there has been a less decided appearance of membrane at the surface in the former.

33. In examining the substance of these soft nerves, as well as that of the brain and spinal chord, I have employed for the most part such as had been preserved in spirit: and, besides using extremely minute portions, I have very often found it needful to avoid adding any covering whatever; the weight of thin mica itself being sufficient to rupture or to flatten it, and thus entirely prevent the structure from being seen. I have already stated it to have been my general practice in these examinations, to add corrosive sublimate dissolved in dilute spirit (par. 7).

34. In the substance of the brain and spinal chord, I have usually met with a very large number of discs (fig. 17 α, β), which from their colour, size, and general appearance (corresponding in these respects with many of the corpuscles within the blood-vessels of the pia mater), seemed to be young corpuscles of the blood. Along with these were rings (γ) and coils of filaments (δ, ε, ε), into which the discs appeared to pass. I have noticed similar rings in the auditory and optic nerves; and coils, as well as rings, in the retina (fig. 18), these coils being of the colour of the blood-corpuscle. Sometimes the coils (fig. 21) are very thick, and comparable to coils of rope.

† Elements of Physiology, translated by Dr. BALY, Part III. p. 597.

‡ Ibid. pp. 597, 598. § Ibid. p. 598.

35. The constant presence in these parts, of discs, rings, and coils, makes it difficult to avoid connecting them with such objects as that in fig. 22: the outer spiral in which, for instance, may represent an advanced state of coils like those in fig. 21. Spirals were present between α and β in fig. 22; but they have not been delineated.

36. In fig. 80 γ, is a broad band-like axis, consisting of delicate longitudinal filaments, and having filaments (β) external to it; these being surrounded by a spiral (α). The broad band-like axis (γ), I think may correspond to that of Remak above referred to; the "white substance" of Schwann being here represented by the filaments β and α. If, however, this analogy exists, my observations go farther even than Remak's. The axis described by this observer was found by him to be susceptible of division into filaments. So also is the one described by myself (fig. 80 γ, 81 β, 85 β). But what I add is that each filament is a compound body, that enlarges (fig. 86), and, from analogy, may contain the elements of future structures, formed by division and subdivision to which no limits can be assigned.

37. The filaments β in fig. 85, being of far minuter size than the so-called "primitive fibre" of the nerves (figs. 102, 112 α, β), I think it possible that the filaments referred to in a former page, as seen by Schwann to proceed from one of the ordinary "primitive fibres" in the mesentery of the Frog, may have had a similar mode of origin.

38. It has been already stated that the filaments which I believe to constitute the "white substance of nervous fibre," are often seen to be, not longitudinal, but curiously interlaced (fig. 102 γ), as though each filament ran in a spiral direction. The appearance has been very much like what would be produced by an elongation of the spirals in fig. 60 (compare this with fig. 102 γ), supposing many spirals to be present instead of two. Now fig. 60, though ideal, represents, apparently, no more than an advanced state of the object fig. 22. In fig. 22 the spirals α and β *run in opposite directions*; and were β to have attained the size of α, we should have fig. 60, with a central row of nuclei for the production of other spirals, which spirals would make the resemblance to fig. 102. γ still more complete†.

39. The frequent interlacing (fig. 102 γ), and apparently spiral direction, of the filaments in nerves, now referred to, seems the more deserving of attention, from my having found spirally directed filaments so very general in the retina, brain, and spinal chord (figs. 17 to 22, 72, 77, 80 to 82, 85, 99). Farther, I have noticed spirally directed filaments, on being broken, to recoil (figs. 80, 81). Such a change in the "white substance," taking place within a tube, might produce varicosities; and those minute isolated masses, hitherto called granular, by which it has been usual to distinguish nerve.

40. In the course of my investigations, I met with a curious object in the lachrymal gland, more resembling a nerve than any other structure, the appearance of which

† As already mentioned, there were spirals between α and β in fig. 22; which I have not introduced. Their presence gives an additional resemblance to fig. 102 γ. From the above remarks, it appears that a state like that in fig. 60 may be produced in two ways. See par. 27.

I am acquainted with. This body, sketched in fig. 118, was composed of flat filaments (β, γ), and had a loop-like termination, to the very extremity of which,—that is, into the loop itself,—the filaments in question were continued, and which indeed they formed. Nothing was seen in this object besides filaments, longitudinal and spiral, for no membranous covering could be discerned. A remarkable crossing of the filaments of opposite sides (α), was noticed between the trunk of this object and its loop.

Facts observed in the Formation and Structure of Muscle.

41. In May 1840, I offered to the Society some remarks on the origin of muscle†, in which it was mentioned that I was then unable to state the mode of formation of the fibrillæ within the cylinder. Subsequent observations, to be presently detailed, seem to throw some light upon that subject. In the mean time, however, a memoir by W. Bowman has been read, "On the Minute Structure and Movements of Voluntary Muscle‡." This circumstance would have inclined me not to return to the subject, but for its essential connection with researches previously begun by myself; namely, those "on the Corpuscles of the Blood:" and in recording the results, I perceive with regret that in the main points they are at variance with the observations of the author just mentioned.

42. The arrangement of cells into a necklace-like object, has been referred to in a former page (par. 20) : and though I have delineated cells in this state in two previous memoirs§, they are sketched in outline in the present paper, fig. 28; which represents cells derived from blood-corpuscles of the Frog. These corpuscles or cells were filled with discs (fig. 29), arisen out of the nuclei of the cells. On the disappearance of the *septa* between the cells, there is formed a tube. In early stages, this tube becomes broken, by manipulation, into fragments (fig. 30); which fragments represent, apparently, an altered state of the original cells. Within the tube there arise other tubes (see the columns in fig. 30), having their origin in the discs with which the original cells were filled. These inner or second tubes (figs. 32, 33) are met with in after stages, no longer breaking transversely into fragments, but easily separating in a longitudinal direction. Within these second tubes are nuclei (figs. 42 to 44 α), which divide, subdivide (fig. 42)‖, and give origin to discs. The discs fill the tube, arranging themselves with curious regularity (fig. 44 β), and in a manner similar to that represented by me in the Philosophical Transactions for 1841¶, as the state of blood-red discs in tubes at the edge of the crystalline lens. These discs appear to undergo changes like those passed through by their progenitors, the corpuscles of the

† In my first paper on the Corpuscles of the Blood, *l. c.*, p. 605.

‡ Philosophical Transactions, 1840, p. 457.

§ Philosophical Transactions, 1840, Plate XXX. figs. 14—17; 1841, Plate XXIII. figs. 135, 136.

‖ We thus find the same process in operation here, which I formerly described as taking place in the so-called "primary" cell,—namely, division of the nucleus.

¶ Plate. XXIV. figs. 145—148.

blood: they become rings (fig. 48 α); the rings pass into coils; and the coils unite, thus forming spirals (γ). The adjacent spirals interlace, from the peculiar arrangement, in relation to one another, of the rows of rings (par. 23). In the space circumscribed by the windings of these interlaced spirals, smaller spirals have their origin; these in turn give origin to others; and so on. An example of this, in a later stage, is afforded by fig. 58. Here, α represents the outer or larger spirals; and β the situation of the inner or smaller ones. The outer spirals gradually disappear, *by entering into the formation of the common investing membrane* discovered by SCHWANN, and in its formed state well described by BOWMAN, who proposes to denominate it the "sarcolemma†." This may perhaps explain the mode of origin of the darker of the longitudinal striæ, three of which are represented in fig. 63 (β, β, β): these being apparently the situations of membranous partitions or *septa* (par. 53), passing into the interior of the fasciculus from the common investing membrane.

43. The process just mentioned, of smaller spirals arising in the space circumscribed by the larger ones, with the gradual disappearance of the latter, seems to be continued in later stages‡. The number of the spirals becomes continually greater, and their size more and more minute (figs. 95, 58, 65), until they reach the number and minuteness represented in figs. 96, 63: and they attain even a smaller size.

44. The outer spirals being formed of the outer or ring-like portions of the discs (fig. 48 α), the inner spirals appear to have their origin in the inner part, or nucleus of these discs: and when the inner spirals in their turn enlarge, and new ones form in their interior, the origin of the new spirals, also, seems to take place in the line of continually renovated nuclei; and so on.

45. Fig. 63. presents a state of the muscle-fasciculus, in which it contains what is denominated the "fibril," of a very minute, though not the minutest size. This "fibril" is no other than a state of the object which I have called a flat filament: and which, as we have seen, is a compound structure. The figure (fig. 55) and description (par. 14) by which I have endeavoured to explain the structure of the filament, are especially applicable to the muscular "fibril." This "fibril" I find to be, not round and beaded, as it has been supposed, but a flat and grooved filament, consisting of two spiral threads, running in opposite directions, and interlacing at a certain point (α fig. 55) in every wind. A transverse section of this filament, as before mentioned, is rudely represented by the figure 8 §.

† SCHWANN is the discoverer of this membrane; but we are indebted to BOWMAN for the only complete description hitherto given of it in a formed state. Its mode of origin however, out of spirals, is for the first time described in the present memoir.

‡ In young fasciculi I have noticed a transverse space to extend far into the interior; which is not the case in those more advanced, the cause being the disappearance of the outer and larger spirals, and the continual formation of inner and smaller ones.

§ I have often seen a filament ("fibril") becoming a *fasciculus* (par. 44). See figs. 56, 57, 84, 64 γ. Enlarged filaments are well seen in the heart of the Turtle.

46. This flat filament is so situated in the fasciculus of voluntary muscle, as to present its edge to the observer (fig. 62); the curves of only one of its two spirals being seen. After removal, also, from the fasciculus, the filament very frequently lies, more or less, upon its edge. It seems to have been the appearance presented by the edge of this filament—that is to say, by the curves of a spiral thread,—that suggested to SCHWANN the idea of longitudinal bead-like enlargements of the fibril, as producing striæ in the fasciculus of voluntary muscle.

47. In my opinion, the dark *longitudinal* striæ are spaces (probably occupied by a lubricating fluid) between the edges of flat filaments, each filament being composed of two spiral threads: and the dark *transverse* striæ, rows of spaces between the curves of these spiral threads. If the *dark* longitudinal striæ are spaces between the edges of flat filaments, it follows that the *light* longitudinal striæ are the edges themselves of these filaments. And if the *dark* transverse striæ are rows of spaces between the curves of spiral threads, the *light* transverse striæ are of course the visible portions themselves of these spiral threads.

48. I repeat, that the longitudinal filament in the fasciculus of muscle, appears to be composed of two spiral threads, only one of which is seen, from the edge of the filament being directed towards the observer. This filament, or its edge, seems to correspond to the *primitive marked thread* of FONTANA; to the *primitive fibre* of VALENTIN, and SCHWANN; to the *marked filament* of SKEY; to the *elementary fibre* of MANDL; to the *beaded fibril* of SCHWANN, MÜLLER, LAUTH, and BOWMAN; and to the *granular fibre* of GERBER.

49. In the Philosophical Transactions for 1840 (p. 605), I suggested that, were the nucleus of the blood-corpuscle the seat of changes such as I had witnessed and described in other cells, the nucleus might produce the muscular fibril. The foregoing observations show that the conjecture then offered has been realized: but, I must add, in a most unexpected manner.

50. The chief physiological inferences deducible from a spiral form of the finest threads of muscle, will I think be obvious. At all events, it would be premature for me to introduce remarks on this subject at any length, before my researches are confirmed by those of other observers. Yet there are two or three conclusions that seem called for, in connection with the foregoing facts.

51. Every one knows that in proportion as a spiral is shortened, the spaces between the curves of the spiral are made smaller, and the diameter of the spiral expands: while, in proportion as the spiral is lengthened, as by removing further asunder its two ends, the spaces between the curves of the spiral are made greater, and the diameter of the spiral is diminished. This may serve to illustrate what takes place in a muscle; which is no other than a vast bundle of spirals: showing that the muscle in contraction should be short and thick; while upon the other hand, in relaxation it should be long and thin (compare α and β in fig. 66).

52. A flattening of "segments" or "particles" in the contraction of muscle†, therefore, seems not to be required: and indeed I have in no instance met with segments or particles, which could undergo this change in form. But fig. 66. affords proof that the change contended for really takes place; this figure exhibiting the appearance of two parts of the same fasciculus, that were actually seen; the one, α, being in a contracted, and the other, β, in a relaxed state: and the difference between these two conditions, was seen to result from a difference in the direction of the spirals. At one part, α, the fasciculus being shortened, the spaces (striæ) between the curves of the spirals were made smaller, and the fasciculus was thick. At the part β, the fasciculus being lengthened, the spaces (striæ) between the curves of the spirals were made greater, and the fasciculus was thin.

53. The edges of the flat filaments ("fibrillæ") in voluntary muscle being directed towards the observer, the flat surfaces of these filaments are in contact with one another (except where *septa* intervene, par. 42). And those parts of the spirals of two filaments, so in contact, fit together with the most perfect exactness and regularity, appearing to overlap one another, as viewed *in situ*. The adjacent parts of spirals thus glide harmoniously into a change of place. It will be seen that the view of a recent author, in regard to "segments," was of this kind; but then he found it needful to suppose adhesion of the segments in some way to one another‡. And he appears to have figured as bead-like segments§, what I consider the overlapping parts of spiral threads.

53½. Many of the drawings that accompany the memoir (figs. 58, 59, 65, 93—95) show that there are states of voluntary muscle, in which the longitudinal filaments ("fibrillæ") take no part in producing the transverse striæ; these striæ being caused by the windings of spirals, within which very minute bundles of longitudinal filaments are contained and have their origin. The spirals are interlaced (fig. 64 α, β, γ). When mature, they are flat and grooved filaments, having the compound structure above described. With the shortening of the longitudinal filaments ("fibrillæ") in muscular contraction, the surrounding spirals—and of course the striæ—become elongated and narrow: while in relaxation, these changes are reversed. The "convoluted filaments" regarded by GERBER as "enigmatical‖," were evidently no other than distorted spirals¶.

54. The spiral form of the ultimate threads of muscle, above described, will I think elucidate several facts already known, but as it appears to me, not satisfactorily explained. Thus, for instance, combined as I find these spiral threads of muscle, and situated one within the other, there cannot well be much difference in their lengths, when the fasciculus is broken off. Hence in part, probably, it is that the fasciculus

† BOWMAN, *l. c.*, pp. 493, 494. ‡ Ibid. *l. c.*, p. 470. § *L. c.*, fig. 10 *b*, *c*, fig. 11.

‖ "Elements of the General and Minute Anatomy of Man and the Mammalia." Fig. 83. Explanation of the Plates, p. 35.

¶ This paragraph was communicated to the Society as a Postscript, Jan. 11, 1842.

usually breaks off short. The membranous partitions or *septa*, above described (par. 42), no doubt contribute to prevent a difference in length. Besides which, fig. 123. shows that there are states in which the flat filaments ("fibrillæ") are shared by more than one surrounding spiral. See the additional observations, par. 119. I would also suggest that the spiral form of the ultimate threads of muscle, shows why it is that, before being broken off, the fasciculus sometimes becomes tapered to a point. An instance of this kind is to be seen in fig. 67, representing two portions of the same fasciculus. In α, the direction of the curves of the spirals is comparatively transverse; and this part of the fasciculus is thick: in β, the direction of the curves becomes more and more oblique, until the fasciculus, rendered in the same proportion thin, terminates at last in a point. A very distensible membrane invests the fasciculus to the extremity; being one of the means by which its spiral contents are held together, during this violent elongation.

55. In a former paper†, I stated that membranes appeared to arise from the coalescence of discs. Fully confirming this observation, I have now to add, that, in some instances at least, the discs first form flat filaments, such as those above described; which filaments become interlaced with other filaments, divide, subdivide, and coalesce to form the membranes. The cellular tissue entering into the formation of the sheath of the spinal chord, we saw to become interlaced for this purpose‡: and in an earlier series of investigations, I found the incipient chorion to present an appearance somewhat the same§. The present memoir contains examples of membrane being formed out of interlacing filaments. Muscle presents an instance of membrane, that of the fasciculus, forming by the interlacement of mere spiral *threads*, many of which are too minute to admit of their structure being investigated. But the larger of these threads present a compound structure (figs. 125, 68), which admits of being traced into the objects I have termed flat filaments: and minuteness is no hindrance to the smallest undergoing a like change. The origin of this membrane out of spirals, may assist to account for its remarkable distensibility, elasticity, and toughness, pointed out by Bowman. This author indeed remarks, concerning it, that though from its minuteness and transparency, "it is difficult to form any decided opinion as to its structure *** it would seem not improbably to consist of a very close and intricate interweaving of threads far too minute for separate recognition." But he adds, that "the matter is very doubtful||."

56. In the mammiferous ovum, we saw the first cells succeeding the germinal vesicle to be few and large; and that there occurred a doubling of their number with every diminution in their size¶. The same process, essentially, we have since found

† Philosophical Transactions, 1841, pp. 209, 230, 243.

‡ Ibid., 1841, Plate XXII. fig. 116.

§ Ibid., 1840, Plate XXVIII. fig. 252.

|| *L. c.*, p. 478.

¶ Philosophical Transactions, 1840, p. 539.

to be in operation in the blood-corpuscle at certain periods †, and in tables of the epithelium ‡. To meet with a re-appearance of anything like this process, however, in spiral fibres, I was not prepared. Yet here also, something of the kind is actually seen. For, as above described, within the space circumscribed by the windings of a larger spiral, there arise smaller ones, which are sometimes two in number. There is, besides, another way in which the process just referred to re-appears. A spiral, originally single, gives origin to others in the interior of its *substance* (fig. 71), and thus, by division and subdivision, gradually acquires considerable breadth (fig. 69), or there may be thus formed several separated spirals (figs. 73, 113 $\alpha\,\alpha$).

57. It will be seen, from the account above given of the formation of the muscular fasciculus, that the young fasciculi have the largest and fewest spirals. In the very young Tadpole, I found a great many fasciculi of this kind: while in the older Tadpole, such fasciculi were less numerous. The fasciculi here presented, generally, an increased number of spirals, with a diminution in their size.

58. I cannot doubt that the larger spirals perform contraction, as well as the smaller. It is probable that the difference between the contractile force of muscles in childhood and in adult age, is connected with the above-mentioned difference in the number of the spirals. Nor is this supposition inconsistent with the fact, that muscle by constant exercise increases in its bulk.

59. My observations on the form of the ultimate threads in voluntary muscle, first made on the larva of a Batrachian Reptile, have been confirmed by an examination of this structure in each class of vertebrated animals, including the scaled Amphibia, and Cartilaginous as well as Osseous Fishes. Such of the Invertebrata, also, as happened to be easily obtainable, were examined, and afforded ample confirmation of those observations. They included animals in the *Crustacea* (Crab), *Mollusca* (Limpet, Clam, Cockle, Mussel, Garden Snail, Periwinkle, Whelk), *Annelida* (Earthworm), and *Insecta* (a kind of Caterpillar).

Facts observed in the Formation and Structure of the Crystalline Lens.

60. In the Philosophical Transactions for 1841 §, I delineated cells, first arranged, like the beads of a necklace, in a line; and then, by the disappearance of the intervening *septa*, forming a tube, the foundation of the fibres of the Crystalline Lens ||.

61. I have now to state, that within this tube there are formed, in the first place discs (fig. 129), and then filaments (fig. 130 α), having precisely the same structure as the filaments of other parts. Nowhere have I obtained more satisfactory evidence, than in the lens, that these filaments are composed of two spiral threads (fig. 131 β, γ), and that the spirals give origin within their winds to other filaments.

62. The toothed fibre discovered by Sir DAVID BREWSTER in the lens ¶, is formed

† Philosophical Transactions, 1841, p. 204.

‡ Ibid., 1841, pp. 223, 224.

§ Plate XXV. figs. 157, 158.

|| I find that this observation was previously made by VALENTIN. See WAGNER's Physiologie: erste Abtheilung, p. 138.

¶ Philosophical Transactions, 1833.

out of an enlarged filament; the projecting portions of the spiral threads in the filament, that is, the apparent segments, becoming the teeth of that fibre. And here it is important to refer to a remark made in a former page (par. 16), that the filament has a tendency to become membranous at the surface, and that it contains within itself the elements of other filaments: both of which qualities may be recognized, as the filament is passing into the toothed fibre.

63. From my observations on vegetable structure, to be presently referred to (par. 68), I venture to anticipate that the toothed fibre noticed by Schwann in the epidermis of a Grass, and considered by him as corresponding to that of Brewster in the lens, will be found to have the same mode of origin.

Facts observed in the Structure of Blood-vessels, Mould, Woody Fibre, Hair, Feathers, &c.

64. In examining the coats of a large blood-vessel, I had noticed the filaments of one stratum to cross those of another stratum at right angles. But what was my surprise, when subsequently directing my attention to the structure of the arachnoid, at the remarkable display of filaments in the vessels of the pia mater (fig. 16.)! There are few parts in which the flat and compound filaments ("fibres"), so constantly mentioned in this memoir, are more easily or more distinctly seen, than here. The coats of such of these vessels as are empty, or nearly so, present an inner stratum of filaments having a longitudinal direction, and an outer filament spirally crossing these. In the coats of such of these vessels as are full, the outer or spirally directed filament is wanting. Vessels with the same structure are met with, having many times the diameter of the largest of those in fig. 16.

65. I saw in the olfactory nerve, blood-vessels having two sets of filaments such as those now described, as existing in the pia mater; and their diameter so small, as to admit the blood-corpuscles in only a single row. It is deserving of remark, that the corpuscles observed in this row, presented indications of division into corpuscles of minuter size.

66. We thus find blood-vessels, the walls of which consist of filaments, having the same structure as those filaments which the blood-corpuscle forms. In connection with the spiral direction of the outer filament in these vessels (fig. 16 β), as well indeed as with many facts recorded in this memoir, I refer to the *rouleaux* in which the blood-corpuscles are seen in the microscope to arrange themselves, as probably indicating a tendency to produce spiral filaments. To form *rouleaux*, corpuscle joins itself to corpuscle, that is to say, ring to ring, and rings, as we have seen (par. 34), pass into coils. The union of such coils, end to end, would form a spiral. But the formation, by the blood-corpuscles, of these *rouleaux*, is no less interesting in connection with facts recorded in a former memoir; namely, that structures, including blood-vessels, may be seen to have their origin in rows of cells derived from corpuscles of the blood.

67. I have noticed very curious resemblances in mould, arising from the decay of

Fig. 1.

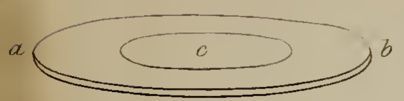


Fig. 3.

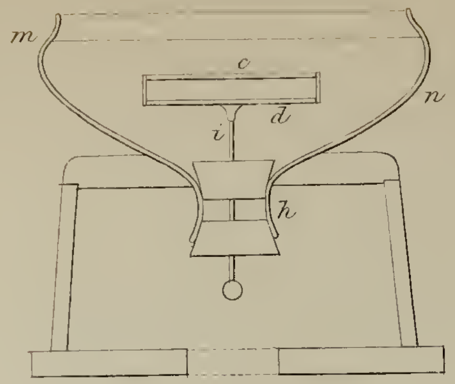


Fig. 7.

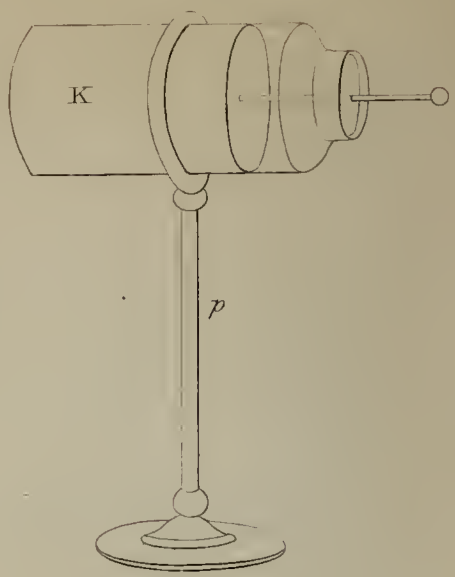


Fig. 2.

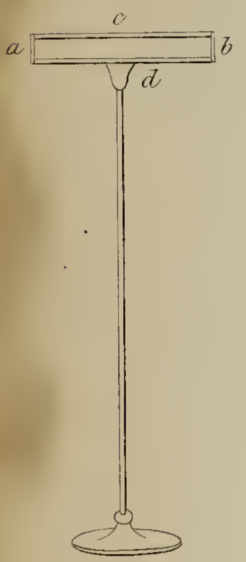


Fig. 9.

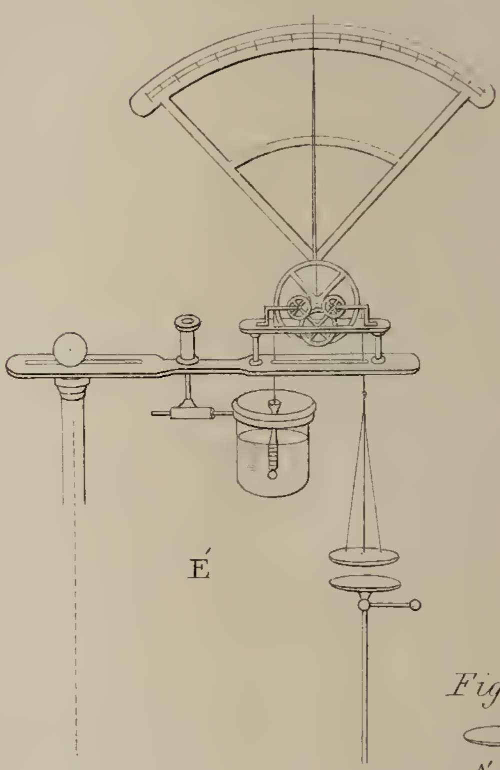


Fig. 8.

Fig. 4.

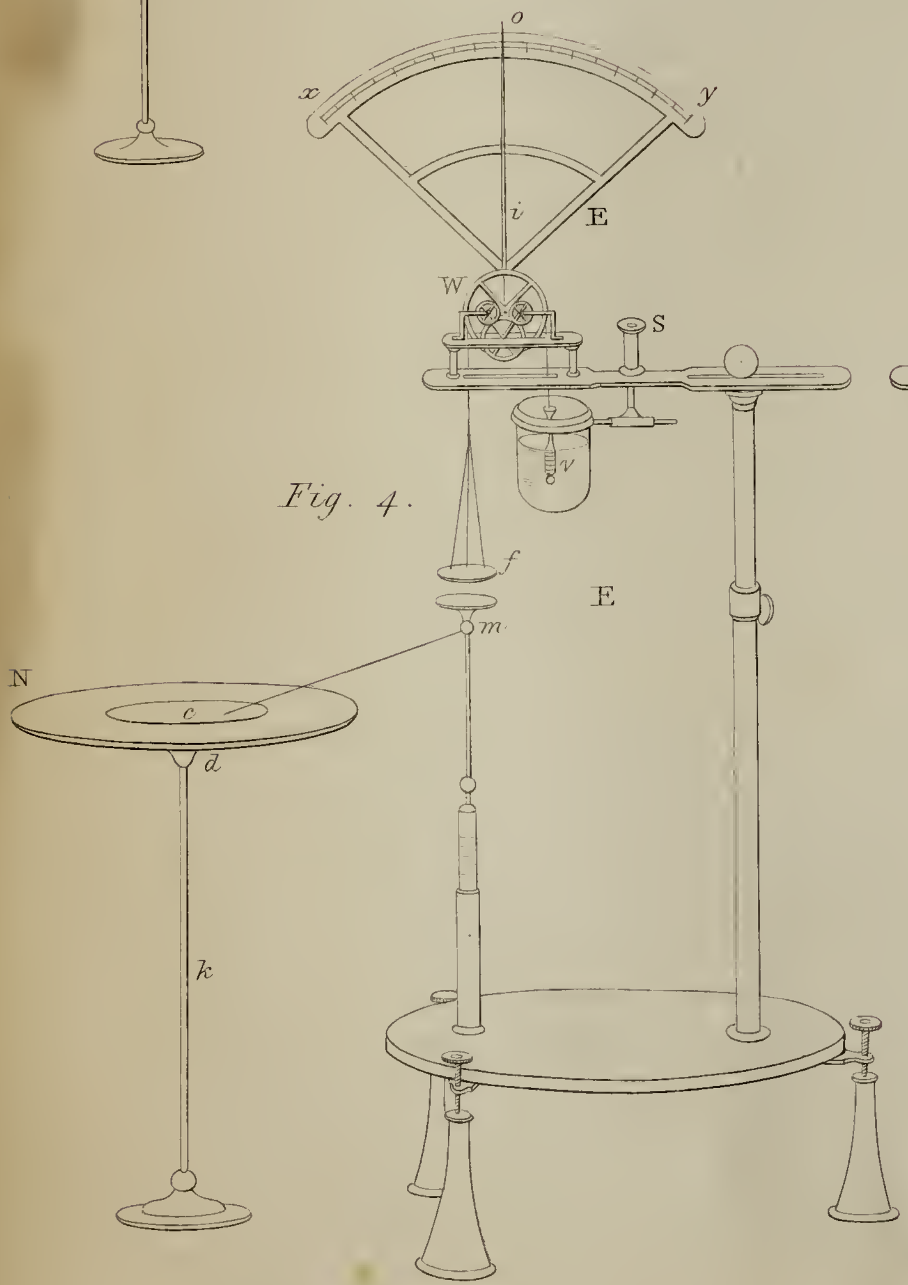


Fig. 6.

Fig. 5.

organic matter, to early stages in the formation of the most elaborate animal tissues, more particularly nerve and muscle. Of such mould, figs. 25, 26, 34, 78, 97, and 104 may serve as examples. They present, it will be seen, mould from a ripe berry, and from decomposing animal substances, including cheese. Some of these figures (figs. 25, 26 β β) represent cells, which have applied themselves to one another, and elongated; in one (fig. 26 γ), discs have arranged themselves in rows; in another (fig. 25), interlacing spirals have formed (out of discs); in a third (fig. 26 δ, ε), there are seen rings; in a fourth (fig. 26 ζ), spiral filaments have been produced, and become elongated; and in a fifth (fig. 78), a bundle of longitudinal filaments is surrounded by one having a spiral form. The plates present very similar appearances, observed in the most important structures of the animal economy.

68. Flax has afforded most satisfactory evidence of identity, not only in structure, but in the mode of reproduction, between animal and vegetable "fibre." We here find the same division of filaments into minuter filaments, and these again into filaments still more minute: as in fig. 76 α, β, γ, δ—states which were noticed in the same fasciculus of flax. There is also seen the same coalescence of some spirals, to form an investing membrane (figs. 109, 110) as is observable in muscle, while others retain the spiral form, and undergo the same division (fig. 113 α) and subdivision (α α). In flax, filaments are frequently met with running in opposite directions around the fasciculus, and forming knots (fig. 101). Some of the flax-fasciculi afford evidence of a continued origin of new spirals in the same centre, after a considerable size has been attained (figs. 109, 110); these spirals being curiously interlaced.—See the description of figs. 109, 110. Very similar appearances, we have seen in nerve (par. 28). All the filaments in flax now mentioned consist of spirals, connected in the manner above described (par. 14), as their mode of combination in animal tissues.

69. The difference in the degree of developement exhibited by a flax-fasciculus in different parts, is sometimes very great. Thus the three conditions α, β, γ, represented in fig. 75, were noticed in the same fasciculus of flax.

70. In cotton, I found appearances of the same kind as those observed in flax†.

71. Hair (fig. 139) presents the same kind of longitudinal filaments, as well as spiral filaments; some of the latter appearing to be curiously interlaced, and others coalescing to enter into the formation of the investing membrane. Besides the hair, of which a sketch is given in the figure, I have examined that of the Bat, Mouse, Mole, Rabbit, Sheep, Hog, Horse, Polar Bear, and Elephant, as well as the hair of Man; finding in all instances the filaments in question.

† It is a little singular, that the flax above mentioned had been spun and woven into the linen cloth used for drying the strip of glass on which the objects lay when examined: portions of these flax-fasciculi detached from the cloth remaining adherent to the glass. I found compound filaments, such as those above described, even in paper, and in dry cork; in Leghorn grass, taken from a hat; in the cedar-wood of a pencil; and in hemp that had been twisted into twine.

72. Certain hairs of plants have presented these filaments with great distinctness. Such has been the case also with the pappus of the *Compositæ* (fig. 126). I have examined the pappus in the Sow Thistle, Common Groundsel, and the Dandelion. In the stinging hair of the Common Nettle (fig. 128), the filament is arranged in a manner connected probably with the properties of this hair: the filament, formed, as in other cases, of two spiral threads, being itself coiled spirally upon the inner surface of each hair.

73. I have rarely seen the filaments in question more distinctly than in feathers from the chick *in ovo*, incubated fifteen days. The quill extremity exhibited them of larger size than the shaft.

74. I recognize spiral threads in the feather-like objects from the wing of the Gnat and Butterfly (fig. 141). In the latter they give rise to both longitudinal and transverse striæ. They are largest at the middle part, near the quill: but it requires close attention, and a very good light, to discern them at all in these objects, so minute is their size, and so closely are they packed together.

75. As already stated (par. 16), many are the instances in which the microscope fails to detect more than a grooved filament; the originally crenate edge presenting an unbroken line. Such is often the case in the Spider's web. Yet here also, filaments composed in the above way, are to be discerned (figs. 142, 143). Tension renders the filaments of this web less distinct; or rather, relaxation makes them more so. Sometimes they are single (fig. 143); sometimes two, three, or a larger number (fig. 142), are combined. Knots are sometimes met with, as though a broken filament had undergone repair.

76. I wound on a strip of glass the cord which a spider was giving off as it descended, for the purpose of making its escape; and found this cord to consist of a single grooved filament, in which a crenate edge was no longer to be seen. It has been already stated, that in one kind of cartilage, I found the nucleus of the cell to present the same appearance as a ball of twine. No doubt it is by a provision somewhat similar, that the Spider is prepared for an emergency such as that now mentioned: and indeed for the formation of its web. This seems much more probable than that the filaments are manufactured at the time when used.

77. When we see a corpuscle enlarging and becoming filled, in one instance with epithelium-cylinders†; in another with objects having the appearance of fat-globules‡; in a third with rudimental ova§; in a fourth with the materials for bundles of spermatozoa‖; in a fifth with columns of discs for the formation of nervous substance¶; in a sixth with like columns for the origin of muscle (figs. 28, 30); and in a seventh with similar columns for forming the mould of cheese (fig. 26 γ),

† Philosophical Transactions, 1841, Pl. XXI. fig. 94.

‡ Ibid. Pl. XXI. fig. 103.

§ Ibid. Pl. XXV. fig. 164.

‖ Ibid. Pl. XXV. figs. 160 to 162.

¶ Ibid. Pl. XXIII. fig. 125.

we cannot but be struck with the great uniformity in type in the earliest stages of formation, however widely different the structures ultimately formed.

78. On a late occasion†, I showed the foundation of the new being, in what are called the highest animals, to have the same structure as that of the simplest plant. We now find this uniformity in type to be recognizable at later periods. For, not only does every tissue seem to arise out of discs having all the same appearance, but the primary arrangement and early metamorphoses of these discs seem to be the same. We recognize the same combination of spiral threads in the mould of cheese, as in the brain of Man. How wonderful the fact, that out of materials so similar, structures should be formed endowed with properties so different!

79. I have had an opportunity of examining the spermatozoon from the epididymis of a person who died suddenly‡. The large extremity appears to me to be a disc, the pellucid depression in which, corresponding apparently to the "sugient orifice" of some authors, is probably analogous to the source of new substance in other discs. Each of the two sides of the peripheral portion of the disc is extended into a thread: these two threads forming, by being twisted, the part usually designated as the tail; an appendage the office of which appears to be to "scull" along to its destination the essential part or disc, and *more particularly its pellucid centre.* The formation of the "tail," as now described, out of two twisted threads, seems to explain the observation of R. Wagner, who, in rare instances, met with the caudal part double (as I suppose, untwisted) at the end. The *caudal* portion of the spermatozoon in the Rabbit presented a similar structure.

On the Structure and Mode of Increase of the Vegetable Spiral.—On the Reticulated Duct, Annular Duct, and Dotted Duct of Plants.

80. Having added to spirals from the leaf-stalk of the strawberry, a spiritous solution of corrosive sublimate (par. 7), I soon discerned in their substance something like a compound structure. In about half an hour, the interior of these spirals presented the appearance at α in fig. 71: that is to say, they were seen to contain two filaments, such as those above described. I therefore consider these spirals to be reproduced in the same manner as those of muscle (figs. 68 to 70 and 73) and of flax (fig. 113 α, α α), which I find to become double and quadruple by self-division.

81. It may be added, that, were the division of the spiral, or at least the separation, to be complete in some parts and not in others, the appearance would resemble that of what is called the "reticulated duct." And the tendency (as it is supposed) of vegetable "fibre" to anastomosis, might be thus explained.

82. Rings have been mentioned (par. 34), as observed in animal structure; which rings divide, and pass into coils. Coils are met with (fig. 22 β) that are equidistant,

† Philosophical Transactions, 1839, p. 372.

‡ For which I am indebted to the kindness of my friend Robert H. Cooke of Stoke Newington.

and in a line. It appears to be by the union of the adjacent extremities of coils, that there is produced the spiral (see the same figure). Corresponding rings and coils in plants, I have not seen nor sought for: but, with so perfect an analogy before me as that above described, I do not find it easy to believe that they can be deficient there. Now were such rings not to form coils, nor even to divide, but simply to enlarge, a line of them, equidistant within a tube, would have very much the same appearance as the "annular duct" of plants.

83. If the appearances delineated in figs. 87, 88, 89, 90, as noticed in the roots of a plant, be compared with those in fig. 25, from mould; in fig. 91, from the cornea of the eye; and in fig. 131, from the crystalline lens; as well as with figures of voluntary muscle in the lower line Plate VIII., and in other Plates, I think it will not be easy to refrain from believing the appearances in all to be produced by the same kind of structure. This structure, in such of the figures now mentioned as were previously referred to, we have seen to possess a spiral form. As already stated with reference to muscle (par. 42), spiral is formed within spiral; and the outer spirals more or less completely coalesce to form a membrane. The vegetable figure, fig. 90, seems to represent an advanced state of such as that in fig. 87. In both, as well as in fig. 88, spirals were observed within a tube. These spirals appeared to interlace with one another; and, by their close contact (fig. 90), to produce the appearance of transverse and elliptical "pores" or "dots." The apparent "dots" or "pores" I believe were no other than spaces between the winds of spirals, contained within a tube. Now spirals *interlacing* in the above way (figs. 87, 88, 90) must, by a longitudinal succession of their winds, produce *septa* (fig. 90 α) in the containing tube. I cannot help believing that these observations will assist to solve the still undecided question, as to the structure of the "dotted duct." In short, I find it difficult to refer the appearance of the "dotted duct" to any cause but that above described, as producing the striæ in voluntary muscle (par. $53\frac{1}{2}$).

84. The filaments in plants have often appeared to me to be so placed, that, by alternate contraction and relaxation, they might influence the contents of cells. And surely the structure of these filaments is sufficient to induce the belief, that they perform an important office in the circulation, including the elevation of the sap. An office of this kind may perhaps belong to spirals in the roots, and elsewhere, such as those in figs. 87 to 90; exhibiting, as some of these do, almost transverse striæ, like those of voluntary muscle in animals.

85. A structure presenting the same appearance as that of the essential part of muscle, being found to pervade, it may be said, all other tissues, it is evident that this structure alone does not account for the contractile property of muscle. To what then is the contractile property of muscle owing? This inquiry my observations do not enable me to answer. It is the duty of an investigator to record the facts he

meets with; difficult as they may be to account for, or even paradoxical as at times they may appear.

86. It seems probable, however, that to the *spiral* structure of the filament ("fibre"), we may attribute the elastic and resilient qualities of certain parts; such as elastic tissue, and cellular tissue, as existing in and under the cutis, and in the parenchyma of the lungs; the latter being intimately connected with the question, whether the lungs are resilient in expiration.

87. Other parts in which the filament is found, as for instance some portions of the cutis, are capable of becoming *constricted.* The existence of filaments may be connected with that constriction.

88. There is, however, one structure in which I have met with the filaments in question, that possesses neither elasticity nor resiliency, nor the property of undergoing either contraction or constriction,—bone. This objection I have not the means of answering: but may be permitted to remark, that although its original developement (the formation of its cartilaginous state) is after the same type, its completion, for a special purpose, is effected by the addition of bone earth.

Analogy between the Tissues of Animals and Plants, after (as well as before) their Formation is complete.

89. The remarkable uniformity in structure between the elements of animal and vegetable tissues, pointed out by Schwann, I showed in the Philosophical Transactions for 1840, to begin with the first foundation of the new being. It will now be seen, I think, from the foregoing observations, that a degree of this analogy between animals and plants exists, not merely in the elements of their tissues, but after the formation of the tissues is complete.

90. That the nucleus of the vegetable cell, instead of being "absorbed as useless," after the formation of the cell-membrane, performs a part not less important than that which I have described as appertaining to it in animals, there can be no kind of doubt. I happen to have incidentally met with the germinal granules of the mushroom (fig. 27), and of the mould of cheese (fig. 26); and have figured them, as presenting evidence of this kind. Too much importance, it appears to me, has been attached, of late, to the *membrane* of the cell; while the source of the contents of the cell, and apparently of all "secondary deposits," that is, the *nucleus,* has been overlooked.

91. It is stated by Valentin that in plants, all "secondary deposits" take place in spiral lines. I have already remarked, that in animals, spirals have heretofore appeared almost wanting. Should the facts recorded in this memoir, however, be established by the researches of other investigators, the question in future may perhaps be, where is the "secondary deposit" in animal structure, which is *not* connected with the spiral form? But more than this: the spiral in animals, as we have seen, is in strictness not a "secondary" formation; it is the most *primary* of all. And the question now, is whether it is not precisely so in plants.

Additional Observations.

Received April 27,—Read May 5, 1842.

92. I have the satisfaction of stating that since the foregoing memoir was presented to the Society, many gentlemen have afforded me the opportunity of demonstrating to them, either with my own microscope, or with instruments made by Powell, Ross, or Smith, the leading facts recorded in it. To one of them (the son of an eminent physiologist, Dr. Bostock) I am indebted for sketches of some of the appearances he saw. Two of these (figs. 145, 146) represent the filament within blood-discs: another (fig. 144) shows a similar filament constituting the muscular fibril. At α, this filament is on its edge: at β, it presents its flat surface. What gives peculiar value to these sketches, is that they were made by one who then for the first time saw the objects in question.

Facts observed in the Coagulation of the Blood.

93. In the examination of coagulating blood, discs are seen having two very different appearances: the one kind comparatively pale, the other very red. It is the latter discs in which a filament is to be found, and which enter into the formation of the clot: the former being merely entangled in it, or remaining in the serum. Observers having directed their attention almost exclusively to the undeveloped discs so remaining in the serum, it is not surprising that they did not discern the filament in question: or that they supposed the blood-discs to be of subordinate importance, and to have no concern in the evolution of the fibrin.

94. In order to see distinctly the filament within blood-discs, some chemical reagent should be added, that will remove a portion of the red colouring matter, without dissolving the filament itself. I have employed for this purpose either the substance before mentioned (corrosive sublimate par. 7), or chromic acid†, or nitrate of silver‡,—and chiefly the last.

95. An objection has been taken to the employment of chemical reagents. It may be replied (as suggested by my brother John T. Barry),—if the point to be proved by the use of chemical reagents had been, that there exists *no visible structure*, then the use of those reagents would have been objectionable, because of their known destructive tendency in a concentrated state. As, however, the point to be proved is, that *a peculiar structure does exist*, it is not too much to assume, that the appearance of a structure so remarkable could not possibly be produced by the chemical action of one of those reagents, the mercurial compound for instance, when it is also

† Sp. gr. about 1·040.

‡ A solution consisting of 1 part nitrate silver in 120 water.

shown that the same structure is rendered visible by other reagents; such as the compounds of silver, and of chrome. It is singular that the objection to the use of chemical reagents should have been mooted by parties in the habit of employing maceration, a process of course highly destructive when prolonged for many days.

96. But the filament may be discerned without any addition whatever, if the coagulation has begun, provided its appearance has become familiar to the eye. In the blood of the Newt when so viewed (i. e. without any addition) the discs containing filaments often resemble flask-like vesicles (fig. 149). The membrane of most of the little flasks exhibits folds or creases (β), converging towards the extremity of the neck. If this extremity is very carefully examined, it is often found that there is a small body protruding (γ): this is no other than the extremity of the filament in question. It is now sometimes possible to discern that the folds just mentioned, mark the situation of the filament within the flask (δ). Occasionally a portion of the filament protrudes, sufficient to admit of its remarkable structure (par. 6) being seen. Sometimes the neck of the flask is bent (β); so that, with the filament, there is produced the appearance of a comma. Still, as before said, for a complete examination of coagulating blood, it is advisable to remove a portion of the red colouring matter by some chemical reagent†.

97. There is considerable variety in the appearance of the red portion of the clot. In that of various Mammals, I have seen the following objects: namely, 1. parent cells‡ (fig. 148 α) filled with young corpuscles, resembling Ammonites; 2. groups of young corpuscles (β), each of which was unwinding into a filament, and comparable to a Turrilite in form; 3. similar objects of larger size (γ), also in groups, as if discharged from parent cells; 4. spiral *fasciculi* of filaments (δ), such as would be produced by the continued elongation and self-division which is represented as incipient in the corpuscles at γ. In other instances, the fasciculus of filaments has seemed to arise directly out of a parent cell; by the simultaneous metamorphosis, into filaments, of all the contained blood-discs.

98. The undulations to be observed in the filaments of "cellular" tissue, seem re-

† When first endeavouring to find the filament in question, the observer should use the clot in blood of the Frog or Newt, three or four hours drawn. Having placed upon a strip of glass a drop of the solution of nitrate of silver, introduce into it a portion of this clot; and with needles break the same into very minute parts; cover these with a piece of thinner glass; press the two glasses firmly together; and view with a power of 400 or 500 diameters. To find the little flasks above described, proceed in the same manner, and use the same clot, but without adding any chemical reagent. Blood (of one of the same animals) should then be examined, first with, and then without chemical reagents, just before its coagulation: and subsequently at various periods during the formation of the clot. I generally employ the Newt (*Lissotriton punctatus* of Bell): and obtain the blood by touching a strip of glass with the part from which the head has been removed; immediately adding a drop of the solution of nitrate of silver, and then a piece of thinner glass. This is done at the end of half a minute, and repeated in one minute, &c. for two or three minutes. The first perceptible changes in coagulation may be thus observed.

‡ These parent cells, usually elliptical, measured in length from $\frac{1}{200}'''$ to $\frac{1}{30}'''$ (Paris line), and were met with even of a larger size. Their colour blood-red.

ferable to a spiral mode of origin, similar to that producing the fasciculus of filaments in the clot fig. 148 δ. And the formation of spirals out of discs in the clot of blood resembles in a striking manner that described in the foregoing memoir, as witnessed in the formation of certain tissues: for instance, nerve and muscle. I have just mentioned the reproduction of filaments by self-division (fig. 148 γ, δ) as noticed in the clot: a process obviously the same as that described in the memoir as observed in the tissues. But the analogy does not end here. In a former communication† I figured blood-corpuscles (cells) from which the contents, except the nucleus, had been removed by acetic acid. If those figures be referred to, it will be found that the nucleus so remaining is in many instances *double*. An examination of coagulating blood enables me now to offer some explanation of this curious fact.

99. In fig. 150 is sketched a blood-corpuscle (cell) presenting a coiled filament, α. This coil having arisen out of the nucleus of the corpuscle or cell, the residual portion of the nucleus became double by self-division: and then each half of the nucleus formed a coil, so that an outer coil contained two smaller coils (β, β), each having a pellucid centre for future change. We here again find a process in operation, bearing a striking resemblance to that producing tissues.—Compare with fig. 147.

100. Where the supply of nutriment goes on, this process of self-division, and the formation of new solid substance, are continued until an entire tissue is produced. Where that supply is soon exhausted, as in coagulating blood, the process in question is speedily at an end. But here also, as in the tissues, greater firmness is acquired as new substance forms. When the supply of nutriment is exhausted, there is no longer a renovation of the nucleus: and now there is seen a cavity (fig. 152 α). This appearance is very frequent in the advanced clot.

101. The best delineations I have met with of coagulated blood, are those by G. Gulliver‡. They are to be explained, I believe, by the facts above mentioned: as well as those given by the same observer of morbid growths§; which, like healthy tissues, have their origin in corpuscles of the blood‖.

102. In the blood-clot, corpuscles are seen of a much minuter size than those usually circulating in the animal. Such corpuscles are constantly met with in the clot of the Frog and Newt. They owe their origin to previous corpuscles; a filament is often to be seen within them; they are frequently membranous at the surface; more or less spherical in form; and generally of a deep red colour.

103. In a former paper, when describing the origin of the various structures of the body in corpuscles of the blood, I mentioned having noticed a reproduction of red

† Philosophical Transactions, 1841, Part II. p. 201. Plate XVIII.

‡ In Gerber's "Elements of the General and Minute Anatomy of Man and the Mammalia," Pl. XXVIII.

§ Ibid. Plates XXIX. XXXI.

‖ Dr. Hodgkin informs me that in some perfectly recent cancerous matter which contained particles in many respects resembling those of the blood of reptiles, he saw great numbers of them having an unequivocal tail-like process appended to them, which was evidently formed from the material surrounding the nucleus.

colouring matter also. The evolution of red colouring matter forms one of the most remarkable changes in the coagulation of the blood (par. 93).

104. The prodigious rapidity with which filaments form during the coagulation of the blood, will be obvious from the short space of time occupied by this process; of which the production of these filaments seems to constitute the leading part.

105. The "notched or granulated fibres" observed by Professor MAYER in the blood†, were possibly my flat, grooved, and compound filaments, a particular description of which has been given in the above memoir; but if so, there is this important difference between the opinion of Professor MAYER and my observations as to their mode of origin. He regards them as representing "free fibrin in the blood," and, from having seen more of them in inflammation, as perhaps the "mechanical consequence of an increased pressure of the blood, by the more rapid and forcible systole of the heart and arteries." He even thinks it possible to produce the same appearances "by drawing the plasma of the chyle into a thread." The filaments I have described are produced in neither of these ways; but, as we have seen, have their origin in corpuscles of the blood.

106. On former occasions‡, I have mentioned these corpuscles as sometimes exhibiting changes in their form. When last referring to this phenomenon, I expressed my conviction that it arose from an inherent contractile power; an idea which repeated observation has confirmed, and which has been strengthened by the very decided opinion of several gentlemen to whom I have shown the phenomenon in question. As I had noticed such an inherent contractile property in blood-corpuscles, it was very interesting to me to meet with moving filaments in some blood from the heart, that had stood for a day or two after death§. And I have since had the further satisfaction to find that the fibres just referred to as seen by Professor MAYER were observed by him in the Lamprey to present free and spontaneous motions.

107. We are indebted to W. ADDISON‖ for the discovery of an immense number of "colourless globules," sometimes observable in the clear colourless fluid at the top of coagulating blood. I have had the opportunity of examining blood presenting, in its coagulation, a top-stratum of clear, nearly colourless fluid; and what I regarded as the "globules" in question. In some blood taken in Pleuritis, I found the number of such "globules" prodigious. They obviously contained discs, the outer of which disappeared on the addition of acetic acid (of the strength of distilled vinegar): and I was not a little interested on finding the residual contents to present the same ap-

† FRORIEP'S Notizen, No. 377, April 1841, p. 42.

‡ Philosophical Transactions, 1840, Part II. p. 598; 1841, Part II. p. 227.

§ The appearance of some of the blood-corpuscles when performing the movements in question, is such as to suggest the idea of a filament being contained within them.

‖ "On colourless globules in the buffy coat of the Blood," Lond. Med. Gaz., 1840, vol. xxvii.

pearances as some of those figured in one of my former communications to the Society, as resulting from the addition of this reagent to corpuscles of the blood†. It immediately became a question with me, whether some of the appearances so delineated were not those of "colourless globules;" a few of which, it is known, are seen floating along with the red discs. I therefore attentively examined blood-corpuscles in very large number, without having added any chemical reagent: and the result is, that I believe the colourless globules, floating with the red blood-discs, to be no other than these discs in an altered state‡. The colourless globules appear to represent different stages in the formation of *parent cells*, which in a former memoir I showed to have their origin in red blood-discs.

108. Acetic acid, then, produced such a change in the colourless globules at the top of the coagulating blood just mentioned, that I believe them to have been of the same kind as certain corpuscles usually floating in the blood: corpuscles paler than the rest, and termed "colourless globules."

109. Are any of the colourless globules in the top-stratum of coagulating blood concerned in producing the buffy coat? ADDISON believes that they "coalesce" to form it. "In a few minutes," says he, "coagulation commenced in streaks and films, all of which were evidently composed by the aggregation of the globules." The optical instrument used by ADDISON was merely a CODDINGTON lens: but the employment of a compound microscope, with very high magnifying powers, has not enabled me to detect any other substance than the globules he pointed out, with the containing fluid, as giving origin to the buffy coat. The fact is, that the globules I met with were no other than *parent cells*, more or less advanced in producing young blood-discs. In the top-stratum I met with a number of these young discs, discharged from their cells, very minute and delicate, and scarcely tinged with red. When the top-stratum had coagulated, these cells were no longer found: but in their stead I saw fibres, such as those in tissues, known to have their origin in cells: not in the cell-membranes, which I find to be of very subordinate importance (par. 90), but in the discs contained within the cells. These fibres were certainly not produced by manipulation§. Among the fibres, nuclei were met with, resembling those in the tissues, which, according to my observations, are descended by fissiparous generation from the nuclei of the original cells (par. 19). In some parts these nuclei were

† Which, I should now add, were obtained by punctures of the finger. See Philosophical Transactions, 1841, Part II. Plate XVII. fig. 23.

‡ The figure just referred to, indeed, represents stages in this transition. See the description of that figure. Thus η had ceased to be biconcave, and become globular: but the nucleus was indistinctly seen, from the surrounding discs and *red colouring matter* having been imperfectly dissolved. Most of the objects there delineated represent *cells*, such as before the addition of acetic acid are filled with discs; only the last formed of which remain visible after the addition of the acid.

§ In a paper of later date than those above referred to, W. ADDISON describes the macerated clot as containing "fibres and filaments, having the toughness, cohesion, and elasticity of organized membrane." Lond. Med. Gaz., March 26, 1841, p. 14. This I fully confirm, from many observations.

less obvious: but I noticed in the same situations minute threads of a spiral form, and am inclined to think that they were the nuclei in an altered state.

110. It is gratifying to me to find in the observations of Dr. REMAK† a confirmation of one previously communicated to the Royal Society by myself (and realizing an idea of Professor OWEN), viz. the reproduction of the blood-corpuscles by means of parent cells‡.

111. Farther, the observations of REMAK led him to believe that the blood-corpuscles of the fœtal chick of the third week are propagated by "*division*." I must here add, that division of the *nucleus* is what I have been long indicating as the mode of reproduction, not only of blood-corpuscles, but of all other cells.

112. It remains to be seen whether my further observation also, that the parent cells are altered red blood-discs, will not be confirmed.

113. According to Dr. HANNOVER, the pale central fibre or primitive band has no concern in producing the varicosities of nervous fibre: and from the observations of Dr. REMAK, it appears that the pale sheath takes no part therein; but that it is the *opaque* sheath ("white substance") that becomes varicose§. This accords with my view (par. 39), that the varicosities result from a rupture in many parts, and a recoiling, of the remarkable filaments of which (according to my observations) the "white substance" is composed||.

114. Since the foregoing memoir was presented to the Society, I have seen the remarkable filaments therein described (par. 6) in "false membrane," in the horny tissue of the hoof, in the chorion and amnion of one of the Mammalia, and in the chalazæ of the Bird's egg. The latter consisted entirely of them.

115. It has long appeared to me questionable, whether the generally received opinion is correct, that the chalazæ consist merely of coagulated albumen to which a spiral form has been given by revolutions of the ovum in its passage through the ovi-

† British and Foreign Medical Review, January, 1842, p. 229. From the Medicinische Zeitung, Juli 7, 1841.

‡ My paper, recording the above observation, was read January 14, 1841. See Philosophical Transactions, 1841, Part II. p. 201. figs. 39, 41 γ, 45 x, 53 β.

§ MÜLLER's Archiv, 1841, p. 512.

|| A friend has pointed out to me a figure by FONTANA, which I am glad to have the opportunity of noticing while the paper is going through the press. It shows, I think, that this observer, sixty years since, discerned traces of the filaments of which I find the "white substance" to be composed. He describes a primitive nervous cylinder as appearing to have "ça et là sur les parois quelques fragmens de fils tortueux." (Traité sur le Vénin de la Vipère, Tab. IV. fig. 1. p. 279.)

Another friend has pointed out to me in a recent work by VALENTIN, that has just come into his hands (SAMUEL THOMAS VON SÖMMERRING, Hirn-und Nervenlehre), a passage which, so far as it goes, agrees with an observation recorded in the foregoing memoir, namely, the formation of membrane out of spiral fibres (pars. 42, 55). VALENTIN states that, under favourable circumstances, it is possible to discern that the delicate membrane surrounding the contents of the nerves is formed of fibres; two of which he describes as appearing to run screw-like around the tube. *L. c.*, p. 5, § 8.

duct. And the observation now recorded, that these structures consist of the remarkable filaments in question, seems sufficient of itself to warrant the belief that they have no such mode of origin.

116. I have already mentioned having seen these filaments in the shell-membrane of the Bird's egg. This membrane I believe is usually regarded as the analogue of the chorion in Mammalia. Now the chorion of the Mammal, according to my observations, has its origin in corpuscles of the blood: and it is not likely that its analogue in the Bird is produced in a different way.

117. On a former occasion†, we saw the incipient chorion, when rising from the "zona pellucida" in the mammiferous ovum, to leave a stratum of unappropriated cells behind it on the "zona," a gelatinous fluid intervening. These cells are subsequently appropriated in the thickening of the chorion. I think it possible that it may be the outer layer of the chorion just mentioned, that is represented by the shell-membrane; while the stratum of cells left for a while on the "zona" in the mammiferous ovum, finds its analogue in the chalazæ of the Bird's egg. If so, it will doubtless be found that the chalazæ also have their origin in corpuscles of the blood; which indeed their structure renders probable.

118. As already mentioned (par. $53\frac{1}{2}$), many of the figures which accompany the foregoing memoir represent states of voluntary muscle, in which the longitudinal "fibrillæ" have no concern in producing the transverse striæ. In these states, the transverse striæ are caused by comparatively large interlacing spirals, which dip inwards in a manner that may be represented by making the half-bent fingers of the two hands to alternate with one another, and then viewing them on the extensor side. The longitudinal "fibrillæ" are contained within the spaces circumscribed by the interlacing spirals.

119. It is in such states of voluntary muscle, that the fasciculus "breaks off short (fig. 157)." This breaking off short is a natural consequence of the interlacing of the spirals; as may be easily shown by a wire model, representing this state of the fasciculus. The fracture of course takes the direction in which there is the least resistance. This direction is the transverse, for in any other there would be a greater number of the curves of spirals to be encountered‡. Sometimes the fasciculus, instead of being "broken off short," is merely *notched* (fig. 157). These two effects of manipulation, however, differ only in degree; the cause producing both being the same§. *This seems to be the explanation of transverse "cleavage."*

† Supplementary Note to a Paper entitled "Researches in Embryology. Third Series: a Contribution to the Physiology of Cells." Philosophical Transactions, 1841, Part II. p. 193.

‡ When the *longitudinal* striæ are exceedingly distinct, the fasciculus does not "break off short." This appears to be owing to the absence now of the investing spirals; which, when present as such, regulate the direction of the fracture. I have already stated them to pass into a membranous form.

§ Occasionally the extremities of the ruptured spirals (figs. 156, 157) may be seen pendent at the part where the fasciculus is broken off or notched.

120. A late observer seems to have regarded the interlacing spirals, now mentioned, as "the edges or focal sections of plates or discs, arranged vertically to the course of the fasciculi, and each of which is made up of a single segment of every fibrilla†." He seems to have mistaken the normal appearances of interlacing spirals, for disturbed states of his supposed "discs." The minute anatomy of the tissues is to be learnt in no other way than by tracing them from their earliest origin.

121. I have in no instance delineated muscle that had undergone maceration, a process open to objection, because putrefactive changes may cause the more delicate portions of a structure to disappear. Can the alleged "beaded" structure of the fibril (which I have never been able to see in *recent* muscle) be demonstrated *without* maceration?

122. This may not be an improper place to draw the attention of future observers, generally, to the effect produced by corrosive chemical reagents, as well as by maceration: whether the maceration be continued so as to produce putrefaction or not. It is easy to imagine that, owing to the operation of either of these, a delicate structure may be entirely destroyed, and therefore unrecognized; or its continuity separated into isolated parts. And I cannot but think that it must be from some such cause as this (the disintegrating effect of prolonged maceration), that Bowman exhibits the fibril of muscle as consisting of beads‡, while my own observations represent it as consisting of a double spiral: and that there is so great a difference between his explanation and my own, of transverse "cleavage." It is true that I also have had recourse to the use of chemical reagents. But there is a wide difference between *the presence* and *the absence* of a visible object immediately after the application of a chemical reagent, when the *peculiar form* of that object entitles it to be considered, not as a chemical compound, but as an organized structure (par. 95).

123. Observers appear not to have determined the mode in which the "fibres" contained in hairs have their origin§. Young hair (wool) of the fœtal sheep presented to me the appearance, an outline of part of which is sketched in fig. 155. The hair-bulb contained nuclei, which seemed to be unwinding, watch-spring-like, into "fibres," that is, flat, grooved, and compound filaments (α), which I have already mentioned having seen in hair (par. 71). These filaments, immediately after being given off from the nuclei, appeared to *interlace*. In the shaft they presented very much the same appearance as those in the olfactory nerve (fig. 108). The interlacing of the filaments produces very remarkable appearances in the shaft of many hairs, as those of the Mouse, Mole, and Rabbit.

† Bowman, *l. c.*, p. 469.

‡ As in "three fragments of a macerated heart." Bowman, *l. c.*, Plate XVI. fig. 17.

§ See Simon, in Müller's Archiv, 1841, Heft IV. p. 369: by whom the researches of Henle, and those of Bidder are referred to.

124. At the commencement of last year, I presented to the Society a communication, in which certain appearances I had noticed in blood-corpuscles were referred to a process of the same kind as that previously described by myself, as witnessed in the germinal vesicle, that is, in the essential part of the ovum. I concluded, that the corpuscles of the blood are generated by a process of the same kind as that giving origin to those cells which are the immediate successors of the germinal vesicle, or original parent cell. The comparison, however, was not then extended beyond the mode of production of young cells.

125. My subsequent researches show that we may go farther. The changes taking place in the ovum lead to the formation of a new being. Those effected in the corpuscle of the blood lead to the formation of a filament, endowed with the property of reproducing itself by division. And what is very remarkable, the position of this filament in the blood-corpuscle bears a striking resemblance to that of the young in the ovum of certain intestinal worms, as remarked by Professor Owen, on seeing my drawings of the filament in corpuscles of the blood†. Is the blood-corpuscle to be regarded as an ovum?

126. Explanation of the Plates.

PLATE V.

Fig. 1. Man. Blood-corpuscles, in blood obtained by a puncture of the finger. Each of them has become a filament, having a coil-like form (par. 1).

Fig. 2. Man. Blood-corpuscles, in blood (obtained by a puncture of the finger) which had stood for some time, between two pieces of glass, in the microscope. Each of them is now a more or less coiled filament. The division of the blood-corpuscle into very minute objects (discs), which may be seen taking place in the microscope, seems to be preparatory to the formation of the filament (par. 25).

Fig. 3. Man. From the coagulum of venous blood, taken in hæmoptysis. α. Filaments, for the most part parallel. β. Blood-corpuscle which has passed into a coiled filament (par. 8).

Fig. 4. From the same coagulum. α. Filaments; β. Rings; γ. Coils, and other objects; all of them altered blood-corpuscles, having the same structure as the filaments α. The whole blood-red. The buffy coat in other blood presented similar filaments, in denser aggregation, and less red (pars. 8, 97).

Fig. 5. Sparrow (*Fringilla domestica*, Linn.). Sketch of blood-corpuscles, each presenting a coiled filament. The figure represents the *structure* of the filament at α (par. 13).

† I have already mentioned that the appearance of some of the blood-corpuscles when exhibiting changes in their form, is such as to suggest the idea of a filament being contained within them.

Fig. 6. Sparrow. From the coagulum of blood. α, β. Blood-corpuscles (coils) unwinding themselves into the straight and parallel filaments of the coagulum (par. 8). The filament β is on its edge (par. 6).

Fig. 7. Chick (*Phasianus Gallus*, LINN.) *in ovo*, incubated twelve days. Sketch of blood-corpuscles (coils), which are unwinding themselves as filaments. α. Parallel filaments, in the same field of view. Blood-red. From the wing. Similar objects seen in the leg (par. 8).

Fig. 8. Turtle. Sketch of blood-corpuscles containing filaments. In all of these corpuscles, the filament is *formed* at the outer part. Between this outer part and the centre, the corpuscles α, β present discs arranged in lines for the formation of a further portion of the filament (par. 25). In the coagulum of blood of the Turtle, the same unwinding of corpuscles into filaments was seen, as is described in the explanation of fig. 10. from the Newt, and in other figures.

Fig. 9. Frog (*Rana temporaria*, LINN.). Sketch of blood-corpuscles containing filaments. α. Even the central part is unwinding itself into a filament. β. Exhibits a spiral arrangement of the filament. γ. Filament on its edge at one part: indistinct at other parts in this corpuscle. δ. Discs, also, seen in this corpuscle: their outer part having very much the appearance of a filament.

Fig. 10. Newt (*Lissotriton punctatus*, BELL.). Sketch of blood-corpuscles containing filaments, which are represented only in certain parts. α. The nucleus is double (pars. $98\frac{1}{2}$, 99). β. The outer part of the nucleus resembles that of a ball of twine, from its consisting of a filament. γ. The nucleus unwinding itself into a filament. δ. The filament on its edge (par. 6). ε. Nucleus removed from its corpuscle. It is unwinding itself into a filament. ζ. Corpuscle giving off a filament from its outer part. η. Filaments, some of them parallel, into which some of the corpuscles have passed. This blood had stood for a while in the microscope (par. 8).

Fig. 11. Toad (*Rana Bufo*, LINN.). Sketch of blood-corpuscles containing filaments. α. The coil-like form of the filament is seen. β. Represents the outer portion of the filament lying on its edge; and rendering this part of the corpuscle thicker than that immediately internal to it; as well as giving to the corpuscle the appearance of being abruptly cut off (par. 2). γ. In a condition less advanced than α: there being in γ more of the central part still in the state of discs (par. 2).

Fig. 12. Skate (*Raia batis*, LINN.). Sketch of blood-corpuscles, each containing a coiled filament. This filament on its edge at the circumference (see the explanation of γ, fig. 11 and par. 2).

Fig. 13. Cod (*Gadus Morrhua*, LINN.). Sketch of blood-corpuscles more or less advanced in giving origin to filaments. α. The formation of the filament is

far advanced; β. the outer part is formed, nucleus double (pars. $98\frac{1}{2}$, 99); γ. no part of the filament yet formed; but discs are arranged in a line for its formation (par. 25).

Fig. 14. Lobster (*Cancer marinus*, LINN.). Sketch of blood-corpuscles, each of which has become a coiled filament (par. 4). α. Structure of the filament (par. 6). At β the filament is on its edge.

Fig. 15. Oyster (*Ostrea edulis*, LINN.). Sketch of blood-corpuscles, each of which has become a coiled filament (par. 4). At certain parts the figure represents the structure of the filament (par. 6).

PLATE VI.

Fig. 16. Rabbit (*Lepus Cuniculus*, LINN.). Sketch of blood-vessels in the pia mater α. Longitudinal filaments, merely dotted in, except that on the left, which represents the structure of the filament (par. 6). β. Outline of a filament spirally investing the longitudinal filaments. γ. Structure of this filament. δ. Blood-corpuscles, chiefly young and of very minute size. ε. Line marking the situation of the inner surface of the vessel (par. 64).

Fig. 17. Rabbit. From the spinal chord. Corpuscles, apparently young blood-corpuscles (α), passing into a compound disc (β), out of which there is formed either a ring (γ) or a coil (δ). The larger coils ε, ε, seemed to be advanced conditions of γ and δ. Colour red (par. 34).

Fig. 18. Rabbit. Sketch of bodies observed in the retina. The general appearance of such bodies is that of rings, having a very high refractive power ("globules" of authors?). But they are coiled filaments, often seen to be formed out of rings such as those in fig. 17. Such objects are red (par. 34).

Fig. 19. Rabbit. From the medullary substance of the brain. Ring-like object or coil, connected, certainly at α and probably at β, with a filament, the structure of which is seen at γ. Blood-red (par. 34).

Fig. 20. Sheep (*Ovis Aries*, LINN.). From the grey substance of the cerebellum. Sketch of coils, which are altered discs, such as β fig. 17 (par. 34).

Fig. 21. Sheep. From the spinal chord†. Coils, arisen out of discs having the appearance of blood-corpuscles. α Was lying on β, and apparently entering, with it, into the formation of a tube (see pars. 34. 35). γ. Structure of the coiled filaments.

Fig. 22. Sheep. From the spinal chord†. Objects such as those in fig. 21 having united to form a tube (α), other spirals come into view in the interior (which indeed are represented in fig. 21). The continually renewed nuclei, unwinding themselves, first in one direction and then in the other, give origin to coils, the adjacent extremities of which unite, and then form

† White substance from the interspace between the posterior and lateral tracts.

spirals. The last formed, or forming, of these spirals is seen at β, together with its structure. γ. Represents the nuclei. Spirals were noticed between α and β, but they are not represented in the figure (pars. 35, 38).

Fig. 23. Chick *in ovo*; twelfth (?) day of incubation. Sketch of a muscle-tube. α. Membrane. β. Nuclei in the centre of the tube: very near together. γ. Spiral. δ. Another spiral appearing to arise from some of the nuclei. See the description of fig. 22 β.

Fig. 24. Rabbit. From the cortical substance of the cerebrum. Blood-red cell arranged to form tubes. These cells are in outline excepting two, in which the contents were seen to consist of discs, or ring-like objects, arranged with regularity, like those in muscle, fig. 45.

Fig. 25. Sketch of mould on a ripe berry (*Rubus fruticosus*, Linn.) that had been kept a few days. Cells having arranged themselves in a necklace-like form, have elongated, and spirals are forming in their interior (par. 67).

Fig. 26. Sketch of mould from cheese. α. Granules, escaped from containing bags. β, β. Tubes, still exhibiting the *septa* between the cells, by the union of which they were formed. One of them is branched. At γ, in one of the tubes, are cell-like objects arranging themselves in lines. δ. Rings now visible. ε. Smaller rings, or interlacing spirals. ζ. Spirals having been formed, they have become very much elongated, so as to appear nearly horizontal (par. 67).

Fig. 27. Mushroom. Sketch of germinal granules, of a reddish brown or purple colour, from the hymenium. In such granules a nucleus is seen, often consisting of two parts. Around the nucleus are other objects, smaller and having a less refractive power. These are not represented, except in α. β. Granule, apparently younger than the rest (see par. 90).

Fig. 28. Tadpole, about 5‴ or less. From the tail. Outline of cells, which are altered blood-corpuscles, arranged in a line to form the first muscle-cylinder or tube (par. 42).

Fig. 29. Tadpole, about $5\frac{1}{2}$‴. From the tail. Corpuscles having the appearance of young blood-corpuscles, as viewed along with many others in a group, apparently escaped together by the rupture of one parent corpuscle. Cells such as those in fig. 28 are filled with young corpuscles or discs, apparently of the kind represented in the present figure (par. 42).

Fig. 30. Tadpoles, $4\frac{1}{2}$‴ to 5‴. From the tail. Fragments consisting apparently of the contents of objects such as those in fig. 28; the discs (fig. 29) in which have arranged themselves in columns. The fragments are for the most part in outline, except β. γ Presented a membranous appearance at the surface, not seen in α and β. α Was of such length as to appear like two of the cells in fig. 28, not separated from one another. δ. Appearance presented by one of the compound discs in the columns (par. 42).

Fig. 31. Tadpole, $4\frac{1}{2}'''$. From the tail. Compound discs resembling those in figs. 29 and 30. The adjacent ones seemed to have united at a certain part, so as to produce a spiral form. The two bodies in this figure appear to be two columns such as those in fig. 30 (par. 42).

Fig. 32. Tadpole, $5'''$. From the tail. Tubes the parietes of which consist of spirals, forming out of discs such as those in fig. 31 (par. 42).

Fig. 33. Tadpole. From the tail. More advanced stage of the same kind of tubes (par. 42).

Fig. 34. Mould, found on the left auricle of a sheep, several days dead. It is almost entirely in outline. The figure represents two parallel and contiguous tubes; each tube lined by what appeared to be smaller tubes. The divisions between the latter are shown by dots. Within the *larger* tubes, there were highly refracting globules (see the figure), varying much in size, and some of them, when first seen, were easily moved in the longitudinal direction of the tube. They probably were contained in a fluid. Within the smaller tubes on the left hand, were seen either rows of discs (γ), or filaments (β). The smaller tubes on the right hand (α) presented a central cavity; these being probably more advanced than the tubes at β and γ.

PLATE VII.

This Plate represents the Formation of Muscle.

Figs. 35 to 44. Chick *in ovo*; incubated twelve days. Early stages in the formation of muscle, from various parts of the body. Very much in outline.

Fig. 35. There are seen parietal nuclei, with orifices in them: these orifices corresponding to the "nucleoli" of authors. At α, the discs are arranging themselves in a spiral form even around the orifice, *i.e.* as soon as formed. A large spiral invests the whole.

Fig. 36. The figure represents the central part of a tube (α) and a spiral (β). At the outer part, in α, are longitudinal filaments. The spiral β surrounded these filaments. The inner part of α is occupied by cells. Each cell has a highly refracting nucleus, and is filled with discs. The nucleus in each cell has an orifice ("nucleolus").

Fig. 37. Mere outline. The nuclei have positions different from those of the nuclei in fig. 36.

Fig. 38. Some of the filaments contained in the tube present their edges, others their flat surfaces to the observer. In the middle of the tube there are nuclei, small and in near approximation. The tube is flat.

Fig. 39. α. Spiral filament. β. Longitudinal filament; parallel to which, are others of the same kind in outline. γ. Nucleus divided into several parts (discs).

Fig. 40. More advanced state of apparently corresponding objects; the filaments enlarged.

Fig. 41. α. The points of contact in the spiral threads, which constitute the filament, beginning to separate. β. This separation more complete (par. 27).

Fig. 42. Appearances, in three instances, of the nuclei in muscle-tube. The dots show merely the breadth of these tubes. We have here evidence of division (α) and subdivision (β) of the nucleus, with a diminution in its size (par. 42). Filaments were very distinct in the tube β.

Fig. 43. Sketch showing some displacement of filaments by the nucleus; and slight enlargement at this part in the breadth of the tube. It is the edges of the filaments that are seen in this figure.

Fig. 44. α. Nuclei and spirals contained in a tube. β. Another part of the *same tube*: its diameter greater; and this part filled with discs, the arrangement of which was regular (pars. 22, 42). These discs quite red, and resembling young blood-corpuscles (par. 42).

Fig. 45. Chick *in ovo*; incubated twelve (?) days. Outline of the extremity of a muscle-tube, and its contents. These were discs, having precisely the same appearance as young blood-corpuscles (par. 42); and they were arranged with great regularity (pars. 22, 42) in the tube (see the explanation of fig. 48).

Fig. 46. Tadpole, $5\frac{1}{2}'''$. From the tail. Muscle-tube containing discs having the same appearance as young blood-corpuscles (par. 42), each of which exhibited bright points near the centre, these denoting the situations of future discs (par. 44).

Fig. 47. Turtle. Muscle-tube from the heart. The tube contains rings linked together, and preparing to form interlaced spirals (pars. 22, 42).

Fig. 48. Tadpole, $5\frac{1}{2}'''$. Muscle-tube. From the tail. α. Rings, arranged with great regularity in the same way as the discs in figs. 45 and 46. β. Structure of the rings. γ. Spirals formed out of such rings (pars. 22, 42). δ. Structure of the spirals. Each ring appeared to contain the elements of future rings (par. 44), not represented in the figure.

Fig. 49. Tadpole, $5\frac{1}{2}'''$. Muscle-tube, in which are seen interlacing spirals, each of which surrounded minuter objects (filaments?).

Fig. 50. Tadpole, about $5'''$. Muscle-filament ("*fibril*") on its flat surface. It measured in breadth $\frac{1}{1000}'''$ (par. 45).

Fig. 51. Young Monoculus. Flat surface of a muscle-filament ("fibril"), observed in the leg, near its extremity (par. 45).

Fig. 52. Turtle. From the heart. Muscle-filament ("fibril") on its flat surface (par. 45). At the lower part the two spiral threads composing it have become unconnected. One of these threads still presents the spiral form.

Fig. 53. Chick *in ovo*; incubated fifteen days. From the leg. Filament, seen with an immense number of other filaments, forming a very large muscle-fasciculus (par. 45).

Fig. 54. Periwinkle. Interlacing spirals. The lower part of α was not very distinctly seen on the left side. β. Similar objects, but larger. They are in outline. γ. Seen with great distinctness (par. 45).

Fig. 55. Scheme, illustrating the structure, apparently, of the objects figs. 40 α, 41 α, β, 52, 54, 56, 83, 84, and of every object termed in this memoir a filament, flat filament, or band, *i. e.* a "fibre" (pars. 13, 14).

Fig. 56. Turtle. Portion of muscle from the heart. It is a filament, composed of two interlaced spirals (par. 45); but very much larger than usual. At α the filament is broadest: at β it is narrower, perhaps from elongation: at γ it is twisted; and it is the (narrow) edge of the filament that is here seen (par. 44 Note).

Fig. 57. Chick *in ovo*; incubated fifteen days. Interlacing spirals. α. Two nuclei, with orifices ("nucleoli"), in the space circumscribed by one of the spirals (par. 44).

Fig. 58. Tadpole, $5\frac{1}{2}'''$. Four spirals visible on one side of the fasciculus; in each of which were seen two filaments (par. 42). An appearance of fibres crossing one another (spirals entering into the formation of the investing membrane?) was observed at the outer part. They are not shown in the figure.

Fig. 59. Tadpole. From the tail. A small muscle-fasciculus, in which are seen spirals surrounding objects, probably filaments, too minute to be examined in this state. On the left side, one of the spirals is ruptured. (par. 42).

Fig. 60. Scheme, showing the structure of objects illustrated by fig. 55, in an altered state (see pars. 27, 38, 39).

Fig. 61. Muscle-filament ("fibrilla") from the iris of a fish, on its flat surface (par. 45).

Fig. 62. Tadpole, about $6'''$. Sketch of the widened or brush-like extremities of two ruptured fasciculi of muscle (par. 119 Note.) α. Two filaments ("fibrillæ"). The inner of these filaments presents its edge only. The outer filament exhibits at the upper part, its flat surface; and at the lower part, its edge: *i. e.* this filament is twisted (par. 45.). Dots represent the situations of the other filaments in these two fasciculi.

Fig. 63. Tadpole. Sketch of a fasciculus of muscle, broken off at the upper part. The transverse and longitudinal striæ, are represented by lines, except at α, where the structure is delineated fully. This part shows the edge of six filaments ("fibrillæ") (par. 45). β, β, β. These longitudinal striæ darker than the rest (par. 42).

Fig. 64. Muscle; α, γ, from the Lobster (after boiling); δ, from the Sheep. α, γ. Interlaced spirals, which are compound filaments. Their structure is seen at β. Dots represent the situation of longitudinal filaments, surrounded by the spirals α, γ. δ. Appearance inducing the belief that the transverse striæ cross the fasciculus in a continuous line, until the parts are more minutely examined (see the objects α, γ, and par. 120).

Fig. 65. Tadpole, 8'''. From the tail. Muscle-fasciculus more advanced than that in fig. 94. It presents on one side four interlacing spirals; each spiral a compound object. Their contents not shown.

Fig. 66. Young Crab. Two portions of a fasciculus of muscle: α. Contracted; and β, relaxed (see par. 52). The arrow shows the longitudinal direction of the fasciculus.

Fig. 67. Tadpole. Two portions of a fasciculus of muscle. α. The edges of four filaments ("fibrillæ") are seen, unchanged. β. Extremity, elongated to a point before being broken. In β, the direction of the spirals is very much altered. The upper part of β may serve to convey an idea of the state of a fasciculus in extreme relaxation (par. 51). β Appeared to be invested by a highly elastic membrane (par. 54). The extreme point of β was at the distance of $\frac{1}{11}'''$ from α.

PLATE VIII.

Fig. 68. Tadpole, $5\frac{1}{2}'''$. From the tail. Appearance near the surface of an object such as the larger of those in fig. 73, after the addition of acetic acid of the strength of distilled vinegar. The discs it presented (fig. 68) seem to have been the essential part of spirals such as the larger of those in fig. 73; the outer part of which had been removed by the acetic acid. α. The discs seemed to be composed of minuter discs (par. 55).

Fig. 69. Tadpole, about 5'''. From the tail. Spirals detached from a fasciculus of muscle; in a quadruple coil (par. 80).

Fig. 70. Tadpole, about 5'''. From the tail. Spirals detached from a fasciculus of muscle; in a double coil (par. 80).

Fig. 71. Strawberry (*Fragaria vesca*, Linn.). Spiral from the leaf-stalk. This spiral is a compound object, containing filaments ("fibres") (par. 80).

Fig. 72. Sheep. From the white substance of the cerebellum. A spiral filament. α. Structure of this filament (par. 35).

Fig. 73. Tadpole, $5\frac{1}{2}'''$. From the tail. Sketch of two sets of spirals; several being parallel in each. The spaces circumscribed by these spirals presented discs; and the spirals exhibited more or less distinct traces of discs in their substance (par. 55).

Fig. 74. Flax, dividing and subdividing into filaments ("fibres"). At α, and in part of β, a membrane-like investment prevented the structure from being seen (pars. 69, 62).

Fig. 75. Similar division of flax. The same fasciculus presented the three states α, β, γ (par. 69).

Fig. 76. Similar division of flax; the states α, β, γ and δ, having been seen in the same fasciculus (par. 69).

Fig. 77. Sheep. From the spinal chord†. Sketch of a fasciculus of nerve. At α, a spiral crosses the entire fasciculus: at β, one half of the fasciculus is crossed by another spiral (par. 39).

Fig. 78. Sketch of mould from a ripe berry (*Rubus fruticosus*, Linn.). It presents a fasciculus of filaments, surrounded by a spiral filament (par. 67).

Fig. 79. Tadpole, about 5'''. Portion of muscle. From the tail, presenting interlaced spirals (par. 45). These are more transversely curved at the upper part, and the object (filament) is therefore wider here than below, where the direction of the curves is more oblique. At a part still lower than the figure shows, the object was as broad as at the upper part of the figure: and here also there was a corresponding change in the direction of the spirals (par. 51).

Fig. 80. Sheep. From the spinal chord†. Sketch of spiral filaments (α), surrounding filaments having a more (yet not perfectly) longitudinal direction (β). Internal to the latter, was a broad "band-like axis" (γ), exceedingly delicate, and consisting of very minute filaments, such as those in fig. 81. (par. 36).

Fig. 81. Sheep. From the spinal chord†. α. Dots, showing the curves of a spiral. These curves presented great irregularity in their direction, which has not been imitated in the figure. β. Delicate "band-like axis" (corresponding to that in fig. 80), consisting of minuter filaments. Spirals seen in the latter (par. 36).

Fig. 82. Sheep (?). From the grey substance of the cerebellum. Sketch of a fasciculus of nerve, consisting of two halves. Two spiral filaments are seen, the one surrounding half of the fasciculus, and the other surrounding the whole of it. The latter spiral is removed from the fasciculus at the lower part (par. 39).

Fig. 83. Sow Thistle (*Sonchus oleraceus*, Linn.). From the root. Sketch of two interlaced spirals, invested by something like a membrane (par. 83).

Fig. 84. Tadpole. Sketch of two interlaced spirals in muscle, forming a very large filament (par. 45). Between α and β, the filament is twisted; presenting here, therefore, a thinner part, its edge.

Fig. 85. Sheep. From the spinal chord†. Sketch of a fasciculus of nerve. The upper

† See the note, p. 120.

or outer part α, is in mere outline. The lower or inner part appeared to correspond to that marked γ in fig. 80, and β in fig. 81; but was in a more advanced state, the filaments (very minute and delicate in figs. 80 and 81) having enlarged, and separated from one another. The spirals in these filaments are represented at certain parts (β) (par. 36).

Fig. 86. Sheep. From the spinal chord †. Sketch of filaments. They represent a state more advanced than those in fig. 85 (β) (par. 36).

Fig. 87 to 90. From the root of the Sow Thistle. Most of the objects represented in these figures, have the appearance of being merely "dotted," when viewed at certain distances (par. 83).

Fig. 87. The tubes sketched in this figure were filled with interlaced spirals, which are represented only at certain parts. In the tube α, the direction of these spirals is unaltered. In β, partly separated from the other tubes, the spirals have been distorted; precisely the change that takes place in muscle (par. 54). γ. Extremity of the tube β, elongated to a point, with a corresponding elongation of the contained spirals. Compare with fig. 67, from muscle, and see the description of fig. 67.

Fig. 88. Corresponding tube, in a state more advanced, and the spirals, therefore, more numerous and smaller. α. Surface of the tube ("dots"). β. Interior (par. 83).

Fig. 89. α. Interlaced spirals, nearly resembling those in fig. 87. β. Interlaced spirals in a distorted state (par. 54). γ. Drawn by reflected light, exhibits interlaced spirals. Compare with figs. 92, 93, and 94, from muscle.

Fig. 90. The tube in this figure presents the appearance, merely, of transversely elliptical, and bright "pores" or "dots;" which in reality are spaces between the curves of interlacing spirals, such as those in figs. 87, 88, and 89, the curves being concealed in fig. 90. The more superficial of the spirals in fig. 90, seem to be coalescing into a membranous substance, which conceals the inner ones. α. One of the "*septa*," formed by the interlacing spirals (par. 83).

Fig. 91. Sheep. Filament consisting of interlaced spirals, from the cornea. The cornea appeared to be wholly composed of filaments in the densest aggregation, and running in every direction.

Fig. 92. Turtle. Interlaced spirals, from the heart.

Fig. 93. Chick *in ovo*; incubated fifteen days. α. Sketch of interlaced spirals in muscle. On the right, at the lower part, are portions of a ruptured spiral, adherent to the rest. The object β represents a young fasciculus of muscle. Compare it with fig. 89 γ, and see par. 83.

† See the note, p. 120.

Fig. 94. Tadpole, about 5‴. From the tail. Young muscle-fasciculus, presenting on one side three interlacing spirals, with their contents. This object very much resembles β of fig. 93, but is larger. The alternation of the inner spirals in a large fasciculus, may be seen by gradually shortening the focal distance.

Fig. 95. Tadpole, 5½‴. Superficial part of a muscle-fasciculus presenting interlaced spirals (par. 42).

Fig. 96. Tadpole, about 6‴. Muscle-fasciculus presenting on one side five interlaced spirals (par. 42). The transverse striæ somewhat distorted by manipulation.

PLATE IX.

Fig. 97. From mould formed on a portion of the heart. α. Tube containing filaments, apparently spirals, running in different directions, and crossing one another. The filaments are dotted merely. It is their edges which are thus represented. β. Tube containing interwoven spiral filaments, in outline except at one part (par. 67).

Fig. 98. From the same mould. The figure represents two parts of a tube, containing filaments. In the part α, some of the filaments are very longitudinal; others more spiral, and interlacing. In the part β, the spiral filaments (δ) are more *transversely* spiral: they seemed to have been broken off at this part, and had perhaps recoiled in consequence (par. 39). At γ, are filaments transversely spiral; and forming a narrow mass, occupying only the middle of the tube. δ. Structure of the filaments.

Fig. 99. Sheep. From the spinal chord†. Fasciculus of nerve. The figure represents only a part of the many spiral filaments seen in this object. Between some of these spiral filaments (α) were enlargements (β). γ. Structure of the spiral filaments, as well of those at α, as of the others. δ, δ. Longitudinal filaments. ε. Central space, much more pellucid than the rest. This central part is the place of origin of new substance. There seemed to be in the interior, filaments interlacing with one another. These are not represented (par. 39).

Fig. 100. Sketch of fasciculi of flax. In α, are seen longitudinal and spiral filaments. In β, the filaments seemed to interlace (par. 68).

Fig. 101. Sketch of a fasciculus of flax; the interior not shown. Here and there, and in some degree at pretty regular distances, it was crossed by transverse filaments running in opposite directions. At α, there were two of these filaments in each direction (par. 68); at β, there was only one. Where these filaments (α and β) were situated, the diameter of the fasci-

† See the note, p. 120.

culus was greater than elsewhere, independently of the presence of the filaments (α and β). In some parts a single transverse filament crossed the fasciculus, without being met by one in the opposite direction.

Fig. 102. Sketches of fasciculi (the "primitive fibres" of authors) in the ischiatic nerve. All that is intended by this figure, is to show the breadths of the fasciculi, and to give some idea of the direction of such of the contained filaments ("white substance," par. 28) as are represented, which is by no means all that were present in these objects. α and γ. Filaments interlacing. β. Filaments more longitudinal. In β, the interior seemed fluid, or nearly so.

Fig. 103. Chick *in ovo*; incubated twelve days. Very young muscle-tube in a state resembling that in fig. 111 (see the description of fig. 111). The longitudinal filaments are all represented by dots except one, which is seen on its flat surface. The spiral filament is in outline.

Fig. 104. Sketch of a fasciculus of filaments from mould on a ripe berry. The same mould as that in fig. 78.

Fig. 105. Sheep. Sketch, showing the diameter, and undulating, soft appearance of two of the fasciculi in the medullary substance of the cerebrum. In one of these, some of the contained filaments are represented.

Fig. 106. Sheep. Sketch of fasciculi from the cortical substance of the cerebrum, wholly composed of filaments. One of these fasciculi, α, is in outline only. In the other, β, filaments are represented; but these are merely dotted in, with one exception, γ. These filaments did not appear tense, but of the same softness as those from the olfactory nerve, fig. 108. δ. Division of the fasciculus into two parts.

Fig. 107. Rabbit. Fasciculus from the optic nerve. It consists of filaments, lying loosely together, and less distinctly circumscribed by a membranous investment than those of the "white substance" in, for instance, the ischiatic nerve (par. 32).

Fig. 108. Rabbit. Fasciculus from the olfactory nerve. See the description of fig. 107, which is quite as applicable here. The appearance is well represented in this figure (par. 32).

Fig. 109. Sketch of a fasciculus of flax. It represents very few of the filaments seen in the interior. α. Membrane at the surface divided at this part. β. Filament having a longitudinal direction. γ. Direction of more oblique filaments. ε. Central body, surrounded apparently by a fluid. In other parts of the fasciculus, ε was not visible. *It appeared to have resolved itself into the interlaced filaments fig.* 110; *each of the threads in* ε *producing several filaments.*

Fig. 110. Part of the same fasciculus of flax as that in fig. 109. α. Division of an investing membrane. In the interior were interlaced, and apparently

spiral, filaments, probably arisen out of part of ε fig. 109. See the explanation of fig. 109. Several of these filaments are represented in the figure, and parts of others are shown in outline. These filaments were tense. The direction of β seemed longitudinal.

Fig. 111. Chick *in ovo*; incubated twelve (?) days. From the leg. A very young muscle-tube in which there are seen five filaments. The figure represents the edges of these filaments. Two of them are close together, and so applied as to produce almost transverse striæ; three are loosely situated in the tube. Such filaments appear to become enlarged into such as those in figs. 40, 41.

Fig. 112. Frog. From a nerve of the leg. α, β. Fasciculi or tubes (the so-called "primitive fibres"). In α, is seen one of the filaments ("white substance," par. 28) which lie loosely together in these tubes. This filament is on its flat surface. Dots indicate the situation of other filaments. In β are represented four of these filaments, all on their edges. The direction of three is oblique. γ. Filament, the structure of which was remarkably distinct. δ. Similar filament, but more minute and on its edge. γ and δ seen in fasciculi such as those at α and β.

Fig. 113. Sketch of a fasciculus of flax. α. Spiral, composed of two filaments, the structure of which is seen at the extremity. Compare with $\alpha\,\alpha$ of the present figure; with spiral from the leaf-stalk of the Strawberry, fig. 71; with that in flax fig. 101; with those in muscle, figs. 69, 70; and see par. 80 on the reproduction of spirals by division. $\alpha\,\alpha$. Spiral running in the opposite direction; and consisting of *four* filaments (see the reference above). The filaments surrounded by the spirals α and $\alpha\,\alpha$, are seen for the most part on their edges, in the figure. They have the same structure as the filaments of the spirals α and $\alpha\,\alpha$. A cavity in the middle of the fasciculus. Acetic acid.

Fig. 114. Rabbit. Filaments found in the retina. The number seen was very great. α. Is on its edge. β. The upper part on its edge; the lower on its flat surface (pars. 6, 14).

Fig. 115. Rabbit. Filaments from the medullary substance of the cerebrum. α. On its edge; β. on its flat surface (pars. 6, 14).

Fig. 116. Rabbit. From the cortical substance of the cerebrum. β, γ. Filaments, the former on its flat surface, the latter on its edge (pars. 6, 14).

Fig. 117. Frog. From the spinal chord. α, α, β. Filaments; α, α, on their edges; β. on its flat surface (pars. 6, 14). γ. Varicose object, the enlargements often at pretty equal distances. I have seen the pellucid central part (nucleus?) of one of these enlargements to run along the object, and pass into another enlargement, which was thus increased in size.

Fig. 118. Rabbit. Sketch of an object noticed in the lachrymal gland (see par. 40).

α. Interlacement of filaments. β. Structure of these filaments. γ. Spirals. δ. Their structure. ε. Outline of trunk; into which ζ passed.

Fig. 119. Advanced state of such an object as ε, fig. 109.

PLATE X.

Fig. 120. Tadpole, about $5\frac{1}{2}'''$. Corpuscles, having the same appearance as young blood-corpuscles, connected like the links of a chain (par. 23).

Fig. 121. Tadpole, about $6'''$. Sketch of muscle-tubes, as seen lying together, several of them exactly parallel, and the whole apparently discharged from a parent structure (par. 42). No more than the most superficial portion of their contents is shown; and this only at certain parts. Some of these tubes (α) present at least two spirals; in another (β) are interlaced spirals; and in a third (γ), there are rings for the formation of interlacing spirals (par. 42). Very weak acetic acid.

Fig. 122. Tadpole, $5\frac{1}{2}'''$. Similar tubes. α. The direction of the spirals is exceedingly oblique. β. Interlaced spirals. δ. The number of spirals appears to be three.

Fig. 123. Tadpole, $5\frac{1}{2}'''$. From the tail. Muscle-fasciculus in which the objects γ are surrounded by spirals, β, in such a manner, that each γ is shared by two of β. α. Larger spiral, common to the foregoing (par. 54).

Fig. 124. Tadpole. Muscle-tube representing different states of the more central (α, β), as well as the conditions of the more superficial (γ, δ) parts. α. Discs not in lines. β. Larger discs, near the centre, and in something like lines. γ. Discs overlapping one another, and in some parts appearing as if linked together. These more superficial than the discs β, and nearly on a level with the interlaced spirals δ; which correspond to γ of fig. 48.

Fig. 125. Turtle. From the heart. Sketch of interlacing spirals. Each spiral is a flat and compound filament; the edge of which filament is directed towards the observer. Every spiral *thread* appears to contain nuclei; and may therefore become a compound filament (par. 55).

Fig. 126. Dandelion (*Leontodon Taraxacum*, Linn.). Sketch of a portion of the pappus. Longitudinal filaments (β) in the interior are represented by dots. These filaments are collected into fasciculi by spiral filaments (α); the longitudinal filaments being represented by rows of dots, their structure is shown at γ.

Fig. 127. Groundsel (*Senecio vulgaris*, Linn.). From the root. α, β. Sketch of filaments. The structure seen in certain of them. γ Represents the structure of the filaments β, and their larger size.

Fig. 128. Nettle (*Urtica dioica*, Linn.). The figure represents, between α and β, the breadth of a hair from the leaf-stalk; and filaments on the inner sur-

face of the hair. γ. Structure of the filaments, and frequent position with reference to the surface. The dots show merely the direction of other of the filaments: this direction being spiral. Their distance from one another is different in different hairs. A similar appearance observed in hairs from the under surface of the leaf and from the stem (par. 72).

Fig. 129. Fœtal Sheep. From the crystalline lens. Sketch of tubes containing discs. A space in the middle of the tubes (see par. 61).

Fig. 130. Chick *in ovo*; incubated fifteen days. From the crystalline lens. Chiefly in outline. α. Composed of filaments, two of which are represented in the figure. β. An object composed of filaments, more of which were present on the right hand than on the left; whence the greater thickness at the former part. The arrow indicates the longitudinal direction of these filaments. At one end of this object (β) are pendent portions, not of entire filaments, but of spiral threads composing filaments; these spiral threads hanging from the extremities of certain filaments where broken off. γ. Portion of a fasciculus of filaments containing a nucleus, which displaces the contiguous filaments. Many such fasciculi are seen in fig. 132. In the nucleus are three discs, with an orifice in each.

Fig. 131. Bream. From the central part of the crystalline lens. α. Two spirals running in opposite directions, the one within the other. β. Two interlaced spirals containing filaments. γ. Two interlaced spirals. δ. Filament enlarging. Certain states of filaments pass into the toothed fibre, discovered by Sir David Brewster (see par. 62).

Fig. 132. Chick *in ovo*; incubated fifteen days. From a more central part of the same lens, as that from which fig. 130 was taken. Sketch of a flat object, folded at β. It was composed of fasciculi, γ, resembling γ of fig. 130. These fasciculi consisted of filaments, among which were nuclei, displacing, as at α, the contiguous filaments.

Figs. 133 to 136. Rabbit. From the cartilage of the ear.

Fig. 133. This figure represents in outline the situations of several cells. The nuclei of these cells are not shown in all of them. In one instance, α, the nucleus resembles a ball of twine (see par. 18). β. Some of the filaments of the intercellular substance. The nucleus frequently elliptical in form.

Fig. 134. Cell, for the most part in outline. The walls composed of interlaced filaments. α. Structure of the filaments. The central portion of the nucleus had divided into two parts (centres), held together in a remarkable manner by interlaced filaments, proceeding from these parts. Possibly this division of the nucleus denotes incipient division of the cell into two minuter cells. Each of the two parts (centres) of the nucleus had its orifice ("nucleolus"); the two orifices

nearly facing one another. Around the orifice were pale discs not yet arranged into a filament (see par. 18).

Fig. 135. Nuclei of two other cells. One centre is seen in the nucleus α, surrounded by filaments. This centre has its orifice. The nucleus β presents several parts, appearing as though held together by interlacing filaments. Yet perhaps this division of the nucleus into several parts denotes incipient division of the cell into as many minuter cells, of which each part of the divided nucleus would have been the nucleus. See pars. 18, 19.

Fig. 136. Outline of two cells, the nuclei of which had escaped. A filament extended from the situation of an unwinding nucleus to the wall of one of the cells.

Fig. 137. Chick *in ovo*; incubated fifteen days. Outline of cells in the cartilage of one of the phalanges (the terminal one). Filaments indistinctly seen at α. In the nuclei filaments were not seen (as in figs. 133 to 136); yet the discs of which the nuclei were composed (β), appeared like rings: and the central portion of the nucleus γ consisted of two halves as in fig. 134.

Fig. 138. Chick *in ovo*; incubated fifteen days. Filament observed in cartilage of a bone of the leg, more advanced than that in fig. 137.

Fig. 139. Outline of the hair of a Caterpillar, containing filaments, one of which is seen at α (par. 71).

Fig. 140. Sketch of part of two feather-like bodies from the wing of a Gnat. α, α. Structure of the filaments in these objects.

Fig. 141. Sketch of feather-like bodies from the wing of a Butterfly. α. The object entire, and young: β. part of an object of the same kind, more advanced. γ. Structure of the filaments in the object α. δ. Structure of spirals producing transverse (as well as longitudinal) striæ in the object β.

Fig. 142. Spider's web. Fasciculus of filaments. The filament α presents its edge at the middle part. Of the other three filaments, two are on their edge, and the third is on its flat surface. Citric acid. (par. 75).

Fig. 143. Spider's web. Filament on its edge. It crossed some feather-like objects from the wing of a Butterfly; part of one of which is represented in outline in the figure. Citric acid. (par. 75).

PLATE XI.

Figs. 144 to 147½ are not drawn on the same scale as the rest. For the first three of these, the author is indebted to a friend. Fig. 147 is taken from a drawing by Dr. Hesse, in Froriep's Notizen, Juli 1840, No. 309, p. 2. It represents part of Dr. Hesse's fig. 5.

Fig. 144. Frog. Sketch of a large muscular fibril from the heart; α, on its edge (interspaces oblique); β, on its flat surface (par. 92).

Figs. 145, 146. Newt (*Triton cristatus*, Linn.). Sketch of red blood-discs containing filaments; α, on the edge (interspaces oblique); β, on the flat surface (par. 92).

Fig. 147. "Transverse section of the tooth of the Ornithorhynchus near the apex, where the tubes have become closer" (par. 99).

Fig. 147½. From Henle. (Allgemeine Anatomie. Lehre von den Mischungs- und-Formbestandtheilen des menschlichen Körpers, 1841. Taf. IV. fig. 5. I.). From the *nervus ischiadicus* of the Frog; "α ausgetretenes Mark, β zusammengefallene Scheide."

Fig. 148. Man. Sketch of objects from the blood-clot. α. Parent cell; filled with blood-corpuscles having the form of Ammonites. β. More advanced states of such blood-corpuscles, discharged from a parent cell, and seen with others lying in a group. They have the spiral form. γ. Similar blood-corpuscles of a larger size, *i. e.* in a state more advanced: the upper one beginning to undergo division. δ. Spiral fasciculus of filaments (par. 97).

Fig. 149. Newt (*Triton cristatus*, Linn.). Sketch of blood-corpuscles from the forming clot. No addition had been made (par. 96). All are flask-like vesicles (par. 96). α. The membrane without folds. β. Folds are seen. γ. The filament protruding. δ. Two filaments visible in the interior: the nucleus apparently giving them off.

Figs. 150 to 152. Sketches of blood-corpuscles, and of filaments derived from them: as seen in the clot of the Frog and Newt.

Fig. 150. Parent corpuscle, or cell, containing a coiled filament (α), which surrounds two young coiled filaments (β, β). A pellucid nucleus in each of the latter (par. 99).

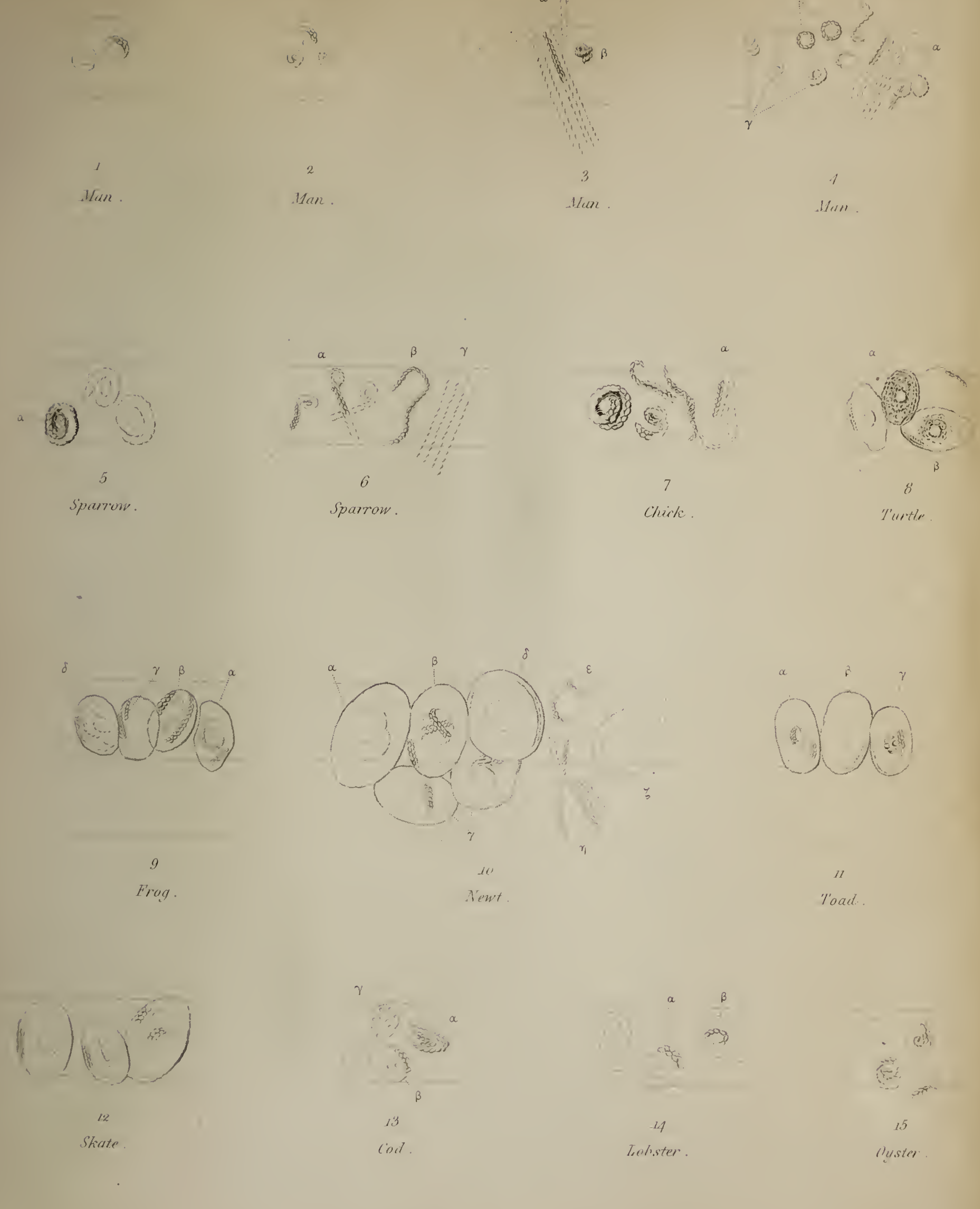
Fig. 151. Parent corpuscle, or cell, containing a coiled filament, which surrounds many young coiled filaments.

Fig. 152. Coiled filaments, derived from blood-corpuscles: α, with a cavity in the centre; β, unwound.

Fig. 153. Sheep. From the clot of blood: nine hours after the bleeding. Sketch of filaments. α. A spiral having been produced, it is elongating. β. The elongation has proceeded farther; and at γ has produced the appearance of a merely twisted filament. Of these filaments, about half a dozen lay abreast, and some of them were united at their extremities. δ. Structure of the filaments. ε. Similarly twisted filaments. ζ. Spiral; apparently an altered red blood-disc. The whole blood-red.

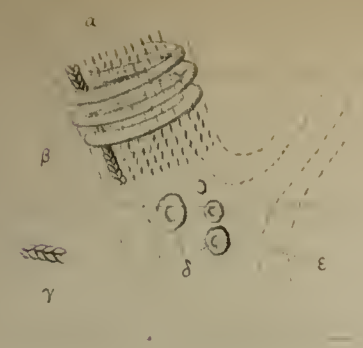
Fig. 154. Newt (*Lissotriton punctatus*, Bell). From the blood-clot. Sketch of an

Fibre.



All the objects are seen of their relative sizes, being alike magnified 600 Diameters. Their actual sizes may be determined by reference to the spaces they occupy between the horizontal lines, which are $\frac{1}{100}$th of a Paris line apart in the micrometer itself. Thus the actual length of α in fig. 5. is $\frac{1}{200}'''$ (Paris line.)

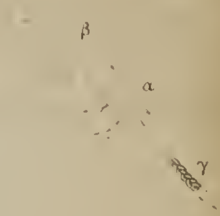
Ad nat. del. Martin Barry.



16
Blood-vessels.

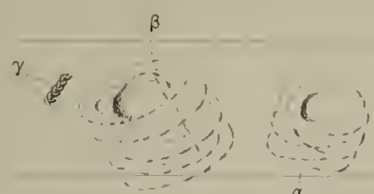
17
Nerve.

18
Nerve.

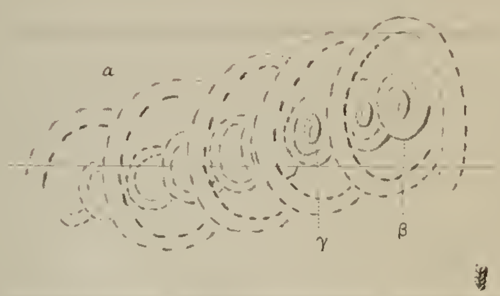


19
Nerve.

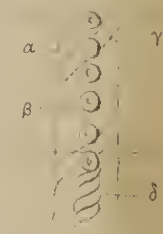
20
Nerve.



21
Nerve.



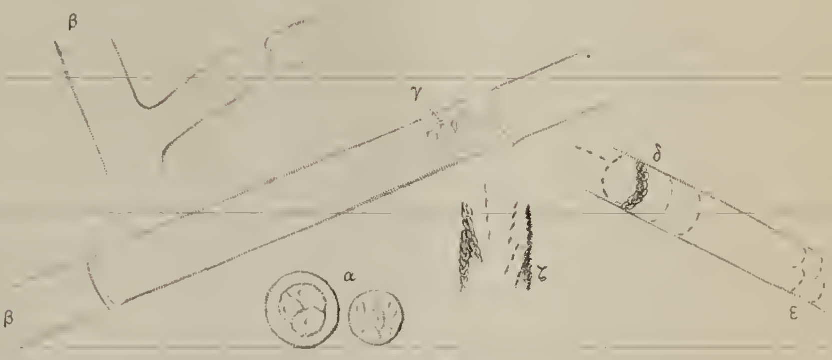
22
Nerve.



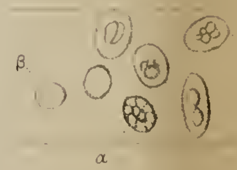
23
Muscle.

24
Nerve.

25
Mould.



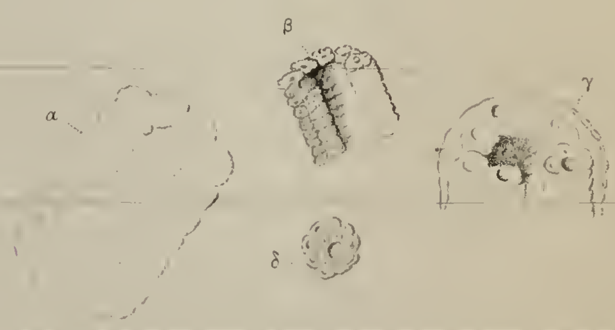
26
Mould from Cheese.



27
Mushroom.

28
Muscle.

29
Muscle.

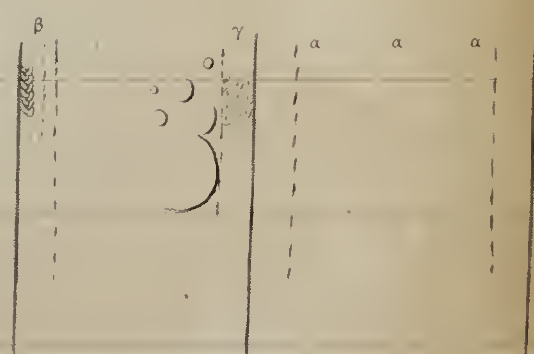


30
Muscle.

31
Muscle.

32
Muscle.

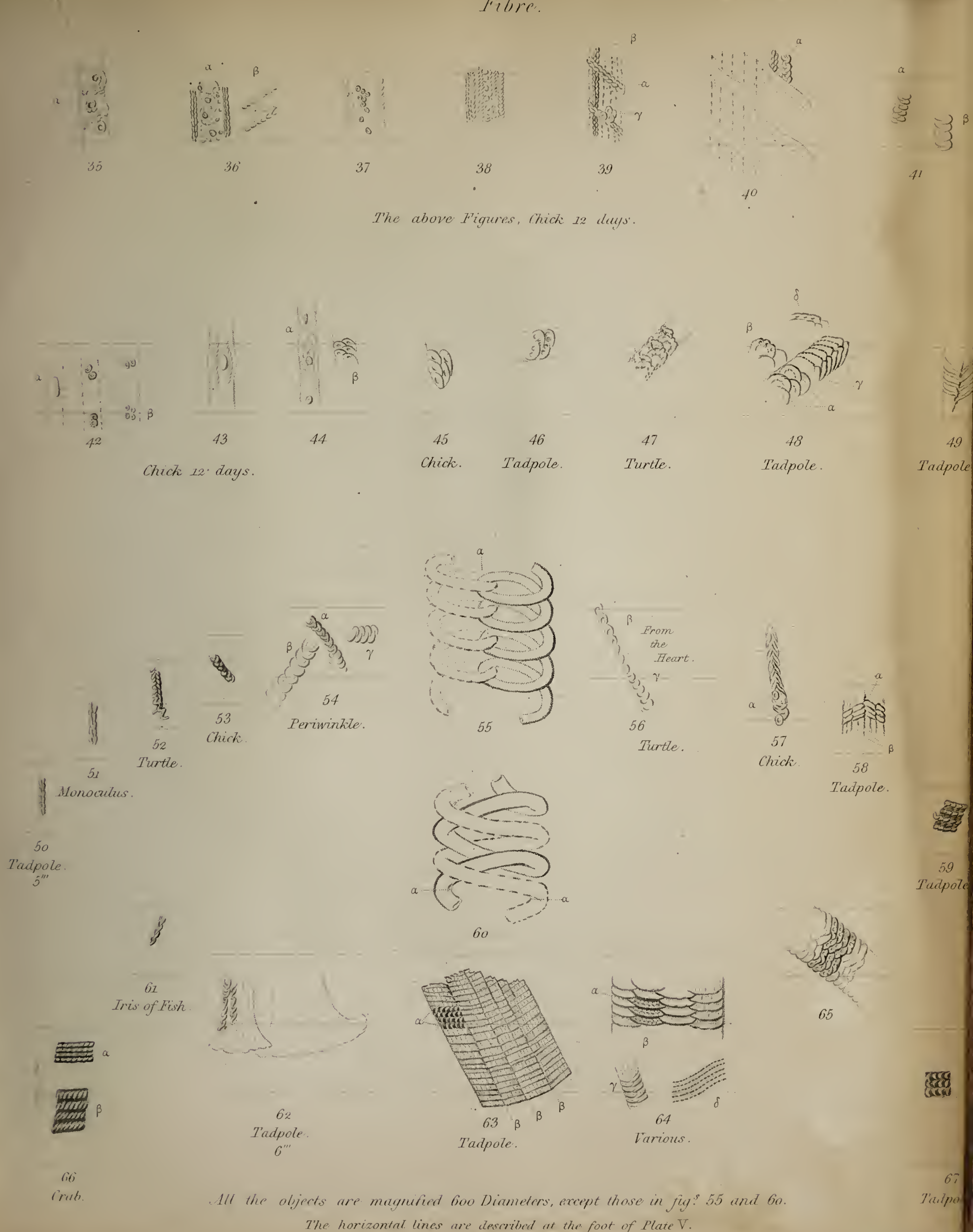
33
Muscle.



34
Mould.

All the Objects are magnified 600 Diameters.

Fibre.



All the objects are magnified 600 Diameters, except those in fig.s 55 and 60.

The horizontal lines are described at the foot of Plate V.

This Plate represents the Formation &c. of Muscle

All the Objects are magnified 600 Diameters.

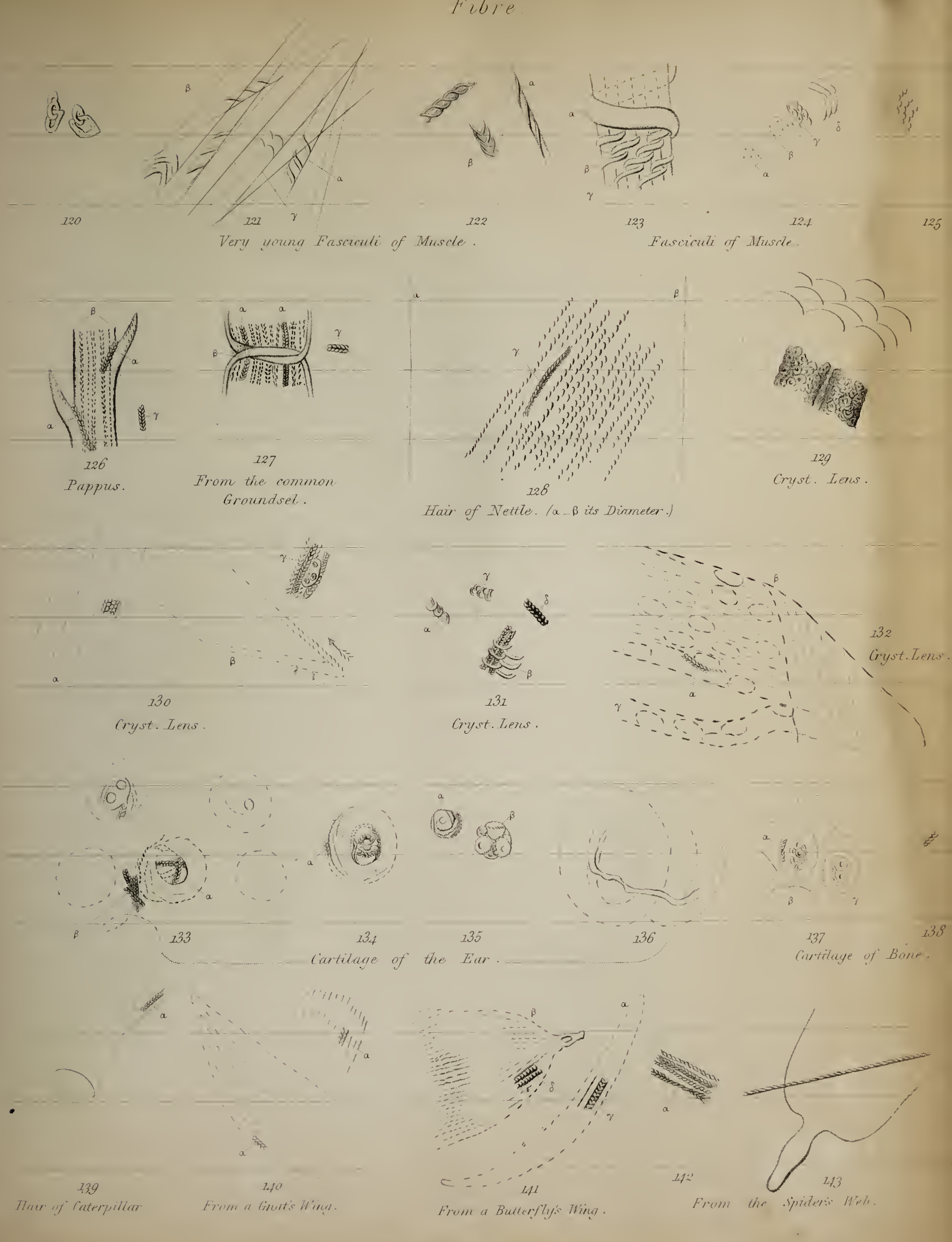
The horizontal lines are described at the foot of Plate V.

Fibre.

All the Objects are magnified 600 Diameters.

The horizontal lines are described at the foot of Plate V.

Fibre.



120, 121, 122 — Very young Fasciculi of Muscle.

123, 124, 125 — Fasciculi of Muscle.

126 — Pappus.

127 — From the common Groundsel.

128 — Hair of Nettle. (α – β its Diameter.)

129 — Cryst. Lens.

130 — Cryst. Lens.

131 — Cryst. Lens.

132 — Cryst. Lens.

133, 134, 135, 136 — Cartilage of the Ear.

137, 138 — Cartilage of Bone.

139 — Hair of Caterpillar.

140 — From a Gnat's Wing.

141 — From a Butterfly's Wing.

142, 143 — From the Spider's Web.

All the Objects are magnified 600 Diameters.

Fibre.

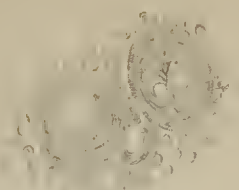
144

Enlarged Muscular Fibril.
(Sketched by J. A. Bostock.)

145

146

Corpuscles of the Blood, containing Filaments.
(Sketched by J. A. Bostock.)

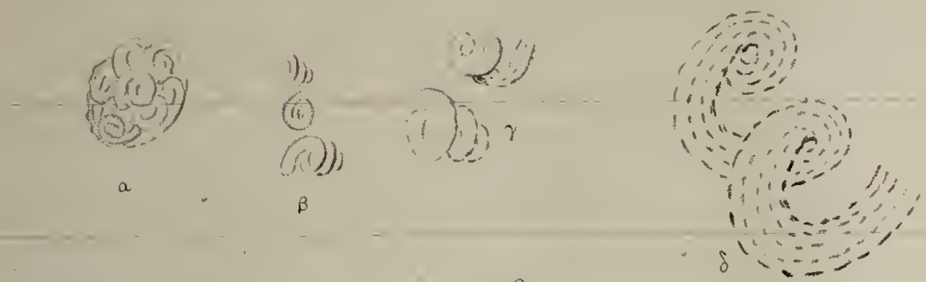


147

Section of a Tooth.
(from Dr. Hesse.)

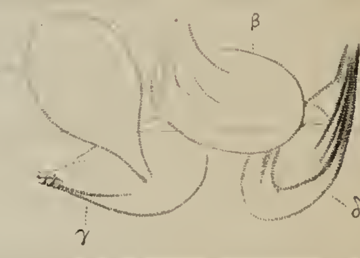
147½

Nerve (from Dr. Henle.)



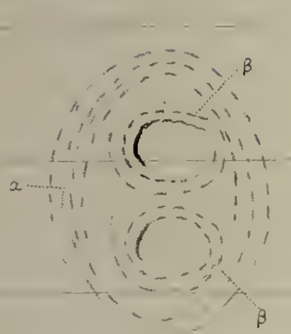
148

Blood-corpuscles passing into Spiral Filaments.
From the Clot of Human Blood.

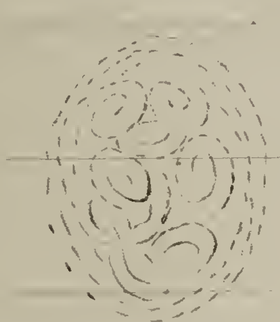


149

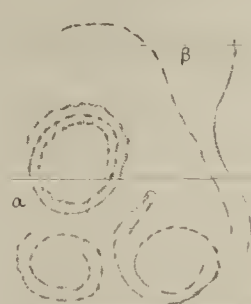
Blood-corpuscles containing Filaments.
From the Clot of the Newt's Blood.



150

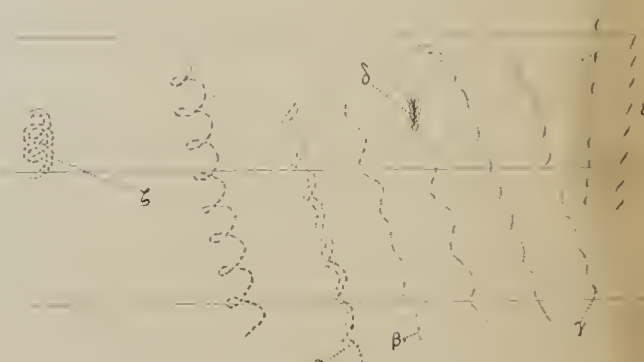


151



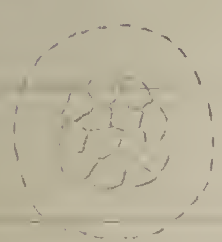
152

From the Blood-clot of the Frog and Newt.



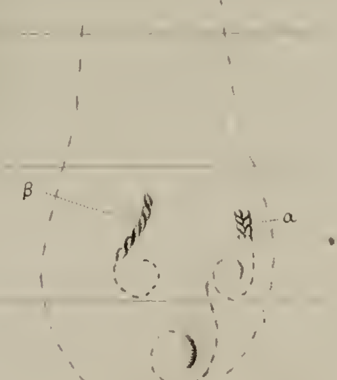
153

From the Blood-clot of the Sheep.



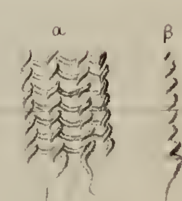
154

From the Blood-clot of the Newt.



155

Hair of the Fœtal Sheep.



156

Voluntary Muscle of the Shrimp.

157

Voluntary Muscle of the Lobster.

All the Objects except those in the upper line are magnified 600 Diameters.

The horizontal lines are described at the foot of Plate V.

Ad Nat. del. Martin Barry

J. Basire sc.

enlarged blood-corpuscle, the nucleus of which was undergoing division, for the purpose of producing young corpuscles.

Fig. 155. Sketch of the hair-bulb in a fœtal sheep; which contained nuclei, unwinding into filaments, the filaments interlacing. α. Structure of the filament, as seen on its flat surface. β. Edge of the filament (par. 123).

Fig. 156. Shrimp. α. Sketch of a fasciculus of voluntary muscle, presenting interlaced spirals; some of which are seen pendent at the lower part. β. One of these spirals, the windings of which were distinctly followed.

Fig. 157. Lobster. Sketch of a fasciculus of voluntary muscle: at the lower part *broken off short*; at the middle part *notched* (pars. 118—122). α, β. Displaced extremities of the ruptured spirals. γ. Structure of the spirals.

METEOROLOGICAL JOURNAL,

KEPT BY THE ASSISTANT SECRETARY,

AT THE APARTMENTS OF THE

ROYAL SOCIETY,

BY ORDER OF

THE PRESIDENT AND COUNCIL.

OBSERVANDA.

Height of the Cistern of the Barometer above the plinth at Waterloo Bridge....83 feet 2 inches.
_______________ above the mean level of the sea ....97 feet.
Height of the receiver of the Rain Gauge above the court of Somerset House ..79 feet.
The External Thermometer is 2 feet higher than the Barometer Cistern.
The Thermometers are graduated to Fahrenheit's scale.
The Barometer is divided into inches and tenths.
The Hours of Observation are of Mean Time, the day beginning at Midnight.
The *daily* observations of the Barometer are *not* corrected.
The *monthly means* are corrected for capillarity and temperature by the Table contained in Mr. Baily's paper in *Phil. Trans.* for 1837.

1841.	9 o'clock, A.M. Barometer uncorrected. Flint Glass.	9 o'clock, A.M. Barometer uncorrected. Crown Glass.	9 o'clock, A.M. Att. Ther.	3 o'clock, P.M. Barometer uncorrected. Flint Glass.	3 o'clock, P.M. Barometer uncorrected. Crown Glass.	3 o'clock, P.M. Att. Ther.	Dew Point at 9 A.M., deg. Fahr.	Diff. of Wet and Dry Bulb Thermometer.	External Thermometers. Fahrenheit. A.M.	External Thermometers. Fahrenheit. 3 P.M.	External Thermometers. Self-registering. Lowest	External Thermometers. Self-registering. Highest	Rain in inches. Read off at 9 A.M.	Direction of the Wind at 9 A.M.	REMARKS.
JULY															
T 1	30.130	30.122	62.6	30.108	30.100	63.8	56	05.4	60.0	63.3	55.4	66.4		S	Lightly overcast—light breeze, with occasional slight rain throughout the day. Evening, The like.
F 2	30.156	30.148	63.3	30.174	30.166	64.8	59	04.3	62.8	68.2	60.0	65.3	.083	W	Overcast—lt. wind throughout the day. Ev. Overcast—light rain.
○ S 3	30.186	30.178	63.7	30.128	30.120	66.7	59	03.8	62.8	72.3	61.3	69.2	.036	N	A.M. Ovct—lt. breeze. P.M. Fine—lt. clouds. Ev. Fine & moonlight.
☉ 4	30.032	30.028	67.8	30.038	30.032	68.7	61	05.7	67.4	68.8	59.3	75.7	.027	S	A.M. Fine—light clouds and breeze—rain early. P.M. Cloudy—slight rain. Evening, Fine and moonlight.
M 5	30.152	30.144	66.2	30.090	30.082	67.9	61	03.3	60.4	68.5	57.9	74.3		N	Lightly overcast—light wind throughout the day. Ev. Overcast.
T 6	29.700	29.696	65.6	29.786	29.778	68.4	62	04.8	63.6	67.3	59.3	69.8	.508	W	A.M. Cloudy—light breeze—very heavy rain early. P.M. Fine—light clouds and breeze. Evening, Fine and moonlight.
W 7	29.946	29.938	69.7	29.830	29.822	67.8	59	06.4	64.3	64.3	55.6	80.3		W	A.M. Fine—lt. clouds & breeze. P.M. Lightly overcast—lt. rain. Ev. Overcast—lt. rain. [Fine & starlight.
T 8	29.830	29.824	77.3	29.890	29.882	67.7	57	05.7	60.8	66.7	55.4	68.6	.069	W	A.M. Fine—lt. clouds & breeze. P.M. Lightly ovct.—lt. rain. Ev.
F 9	30.012	30.004	69.2	29.996	29.988	66.7	55	04.4	59.4	66.8	52.2	78.3	.077	NW	Fine—light clouds and breeze throughout the day. Ev. Early part cloudy—light rain—the latter part fine and starlight.
S 10	29.994	29.986	74.8	29.832	29.824	67.5	54	06.0	60.8	67.7	51.6	74.6	.041	NW	Fine—light clouds and breeze throughout the day. Evening, Overcast—light rain and wind.
☉ 11	29.286	29.280	72.3	29.364	29.360	64.0	53	04.7	57.3	59.0	51.6	69.7	.277	W	A.M. Cloudy—light breeze—very heavy rain, with high wind in the night. P.M. Showers. Ev. Cloudy—brisk wind.
M 12	29.636	29.630	67.7	29.644	29.638	65.0	53	07.6	59.7	63.7	50.8	66.3		W	A.M. Fine—lt. clouds—stiff breeze. P.M. Showery. Ev. Overcast.
T 13	29.686	29.680	68.8	29.724	29.718	65.8	53	07.2	60.7	62.7	49.8	74.6	.044	S	Cloudy—light breeze, with occasional light showers throughout the day. Evening, Fine and starlight.
W 14	29.764	29.756	72.2	29.676	29.668	64.4	56	07.1	60.7	59.8	51.6	68.2		S	Cloudy—light breeze, with occasional light showers throughout the day. Evening, Overcast—light rain.
T 15	29.710	29.702	71.6	29.756	29.748	62.8	54	06.4	60.3	57.7	52.0	65.7	.088	SW	A.M. Fine—light clouds and breeze. P.M. Overcast—hail, rain, thunder, & lightning. Ev. Steady rain. [Fine & starlight.
F 16	29.936	29.930	63.7	29.972	29.964	62.6	54	05.7	58.0	63.2	53.0	64.2	.772	NE	A.M. Fine—lt. clouds & breeze. P.M. Cloudy—very slight rain. Ev.
S 17	30.074	30.068	71.7	30.004	29.996	64.8	55	06.8	62.2	68.8	52.3	69.0		E	Fine—light clouds and breeze throughout the day. Ev. Cloudy.
● ☉ 18	29.698	29.694	62.0	29.740	29.736	62.0	55	05.5	60.5	60.9	54.0	71.6		NNE	A.M. Overcast—lt. rain—brisk wind. P.M. Ovct. Ev. Fine & starlight.
M 19	29.854	29.848	63.9	29.876	29.868	65.7	59	07.3	63.7	69.7	54.6	65.2	.016	S	A.M. Fine—light clouds and breeze, with very slight rain. P.M. Fine—light clouds and wind. Ev. Fine and starlight.
T 20	29.732	29.724	62.7	29.600	29.594	63.3	59	04.4	59.3	61.3	57.2	73.6	.025	S	Overcast—high wind, with light steady rain throughout the day. Evening, Overcast—high wind.
W 21	29.526	29.518	63.2	29.530	29.524	64.3	59	04.5	61.2	64.6	57.6	63.6	.213	S	A.M. Cloudy—high wind, as also high wind with rain throughout the night. P.M. Showers—high wind. Ev. Cloudy.
T 22	29.776	29.772	63.3	29.800	29.794	64.0	58	05.9	60.3	61.8	55.4	67.2	.108	NW var.	A.M. Fine—lt. clds.—stiff breeze. P.M. Cldy. with showers. Ev. Cldy.
F 23	29.982	29.974	67.8	30.016	30.008	63.3	54	05.0	57.8	60.8	54.2	65.3	.105	NW	Cloudy—light brisk wind throughout the day. Evening, Overcast.
S 24	30.152	30.144	60.3	30.188	30.180	62.3	55	03.3	55.7	60.3	54.2	63.0		NW	Overcast—light breeze throughout the day. Evening, The like.
☉ 25	30.180	30.174	60.6	30.138	30.132	63.2	54	03.0	57.6	65.7	54.6	61.7		N	Lightly overcast—lt. breeze throughout the day. Ev. Lightly Cldy.
M 26	30.130	30.122	61.0	30.090	30.082	64.0	56	03.2	59.5	70.0	57.0	67.8		N	A.M. Overcast—lt. breeze. P.M. Fine—lt. clouds & breeze. Ev. Cldy.
T 27	30.052	30.044	67.3	30.022	30.016	66.0	59	03.0	65.3	65.2	59.8	71.4		W	Overcast—thick haze—lt. breeze throughout the day. Ev. Overcast.
W 28	29.876	29.872	63.0	29.840	29.834	65.0	60	01.5	62.5	65.2	55.2	70.5		W	A.M. Overcast—very slight rain—brisk wind. P.M. Fine—light clouds and wind. Ev. Fine—brisk wind.
T 29	29.802	29.798	70.0	29.760	29.754	64.4	54	05.5	59.5	63.0	52.0	63.0		W	Heavy clouds—brisk wind nearly the whole of the day. Evening, Slightly overcast—brisk wind.
F 30	29.754	29.750	64.0	29.712	29.708	63.0	51	06.5	57.7	59.4	51.5	66.0	.027	NW	A.M. Fine—lt. clouds & wind. P.M. Overcast—lt. wind. Ev. The same.
S 31	29.622	29.616	62.2	29.626	29.620	61.6	52	06.5	58.8	57.8	52.0	62.0	.008	W	Overcast—heavy clouds—light wind throughout the day. Evening, Light rain and wind.
MEAN.	29.883	29.876	66.4	29.869	29.862	64.9	56	05.2	60.7	64.3	54.8	68.8	Sum. 2.524		Mean Barometer corrected .... 9 A.M.: F. 29.786, C. 29.778; 3 P.M.: F. 29.776, C. 29.768
AUGUST															
☉ 1	29.830	29.826	62.0	29.918	29.914	61.4	54	05.0	58.3	59.8	50.0	65.2	.055	NW	Heavy clouds—light wind, with showers throughout the day. Ev. Fine—light clouds and wind.
○ M 2	29.986	29.982	63.0	29.938	29.932	63.0	55	06.5	62.5	66.4	54.0	64.0	.005	WSW	Fine—lt. clouds & wind throughout the day. Ev. Overcast—heavy rain.
T 3	29.742	29.738	62.0	29.684	29.680	67.0	59	03.0	62.8	68.5	60.4	70.8	.377	NNW	A.M. Overcast—light wind. P.M. Fine—light clouds. Evening, Overcast—heavy rain during the night.
W 4	29.492	29.488	64.0	29.736	29.730	66.0	58	03.5	60.0	66.2	59.0	71.0	.366	N	Overcast—brisk wind throughout the day. Evening, The same.
T 5	29.796	29.790	67.0	29.714	29.708	65.0	61	04.8	65.0	63.5	60.0	69.0		SW	A.M. Heavy clouds—very brisk wind. P.M. The same, with light rain. Evening, Overcast—brisk wind.
F 6	29.748	29.744	63.0	29.874	29.868	65.0	57	03.0	60.6	66.0	58.5	66.0	.008	W	A.M. Overcast—light wind. P.M. Fine—light clouds and wind. Evening, Overcast—rain—light wind.
S 7	29.962	29.958	65.0	29.912	29.906	66.0	57	06.0	64.0	69.5	60.5	69.5	.088	W	A.M. Heavy clouds—lt. wind. P.M. Fine—lt. clouds & wind. Ev. Overcast—brisk wind. [overcast.
☉ 8	29.738	29.732	64.0	29.692	29.688	65.0	59	02.0	61.0	66.0	59.5	71.4	.008	SSW	Overcast—lt. wind throughout the day—slight rain early. Ev. Slightly
M 9	29.646	29.642	64.2	29.690	29.686	65.5	57	05.3	59.5	64.0	56.0	69.0		W	Lightly overcast—light wind throughout the day. Ev. Fine—light clouds—brisk wind.
T 10	29.874	29.870	70.5	29.870	29.866	64.5	56	07.0	61.0	64.0	53.0	72.5		SW	A.M. Fine—light clouds—brisk wind. P.M. Overcast—brisk wind. Evening, Overcast—rain—high wind.
W 11	29.512	29.506	63.0	29.530	29.526	64.6	59	02.0	61.4	62.4	58.0	67.5	.277	SW	A.M. Overcast—brisk wind—heavy rain early. P.M. Overcast—heavy showers—brisk wind. Evening, Overcast—brisk wind.
T 12	29.958	29.954	66.0	29.976	29.972	64.0	51	07.0	59.2	63.0	51.0	68.0	.080	W var.	A.M. Ovct.—brisk wind. P.M. Fine—lt. clds.—brisk wind. Ev. The like.
F 13	29.928	29.924	61.0	29.878	29.872	62.0	56	06.0	62.0	63.0	61.5	64.0	.013	W	Overcast—brisk wind throughout the day. Ev. The like, with rain.
S 14	29.646	29.642	62.0	29.708	29.702	65.0	58	03.5	62.0	66.0	57.0	66.5	.213	SW	A.M. Heavy clouds—light wind. P.M. Fine—light clouds—brisk wind. Evening, Fine—brisk wind.
☉ 15	29.766	29.760	65.0	29.760	29.756	65.0	59	07.0	64.5	67.2	57.0	68.6	.036	W	A.M. Fine—heavy clouds—brisk wind—rain early—occasional light rain. P.M. Fine—lt. clds.—brisk wind. Ev. Heavy clds.—lt. wind.
● M 16	29.928	29.924	64.0	29.956	29.950	65.0	57	04.5	61.5	70.0	56.0	71.6	.011	WNW	A.M. Overcast—light wind. P.M. Fine—light clouds. Ev. The like.
T 17	30.018	30.014	64.0	30.050	30.046	66.0	60	04.0	64.5	70.0	60.0	71.5		SW	Overcast—brisk wind throughout the day. Ev. Fine, with brisk wind.
W 18	30.210	30.204	65.0	30.220	30.216	66.0	60	05.0	63.7	68.5	58.4	73.0		NW	A.M. Overcast—lt. wind. P.M. Fine—light clouds. Ev. The like.
T 19	30.276	30.270	66.0	30.214	30.210	67.0	57	06.0	63.5	72.0	56.0	69.5		WSW	A.M. Lightly overcast. P.M. Fine—lt. clouds. Ev. The like.
F 20	30.006	30.000	67.6	29.884	29.880	68.0	59	06.5	66.5	75.6	56.0	73.0		SSE	Fine—light clouds—brisk wind throughout the day. Ev. The like.
S 21	29.684	29.680	68.0	29.758	29.754	69.0	63	05.0	66.7	70.8	53.0	77.5		W	Fine—light clouds—brisk wind throughout the day. Ev. The like.
☉ 22	29.978	29.974	67.0	29.972	29.968	67.0	56	04.0	63.0	66.2	56.0	73.0		SW	Very heavy clouds—brisk wind throughout the day. Evening, Heavy rain—brisk wind.
M 23	29.904	29.900	64.0	29.920	29.914	65.4	57	03.0	58.0	66.2	57.0	68.0	.416	WNW	A.M. Overcast. P.M. Fine—light clouds. Evening, The like.
T 24	30.124	30.118	65.0	30.156	30.150	64.5	48	05.5	57.0	63.6	50.5	67.5	.013	WNW	Fine—light clouds and wind throughout the day, with occasional showers. Evening, Lightly overcast.
W 25	30.148	30.142	61.0	30.102	30.098	63.0	—	01.5	57.0	62.7	52.0	65.0	.130	SW	Overcast—light wind throughout the day, with occasional rain. Evening, Overcast.
T 26	30.268	30.262	63.0	30.282	30.278	65.0	61	02.5	63.2	73.2	57.0	65.5	.061	W	Overcast throughout the day. Evening, Fine.
F 27	30.332	30.326	68.0	30.274	30.270	69.0	64	03.3	69.7	74.0	65.0	70.0	.011	W	Fine—light clouds and wind throughout the day. Ev. The like.
S 28	30.264	30.258	68.5	30.226	30.220	69.0	59	03.5	62.7	71.0	59.5	76.5		W	A.M. Lightly overcast—light wind. P.M. Fine—light wind. Ev. The like.
☉ 29	30.236	30.230	68.2	30.150	30.144	69.0	62	03.5	65.4	75.5	59.0	72.5		WSW	A.M. Light fog. P.M. Fine—light clouds. Evening, The like.
M 30	30.064	30.060	68.6	29.956	29.950	69.0	60	03.5	63.5	74.5	60.0	77.0		W	A.M. Overcast. P.M. Fine—light clouds. Evening, The like.
T 31	29.826	29.822	68.8	29.814	29.808	69.6	63	05.0	66.7	70.0	63.0	76.0		W	Lightly overcast throughout the day. Evening, The like, with very slight rain.
MEAN.	29.932	29.927	65.1	29.929	29.925	65.8	58	04.5	62.5	67.7	57.2	70.0	Sum. 2.168		Mean Barometer corrected .... 9 A.M.: F. 29.838, C. 29.832; 3 P.M.: F. 29.833, C. 29.828

The observations for AUGUST were not taken by the Assistant Secretary, on account of absence.

METEOROLOGICAL JOURNAL FOR SEPTEMBER AND OCTOBER, 1841.

1841.	9 o'clock, A.M. Barometer uncorrected. Flint Glass.	9 o'clock, A.M. Barometer uncorrected. Crown Glass.	9 o'clock, A.M. Att. Ther.	3 o'clock, P.M. Barometer uncorrected. Flint Glass.	3 o'clock, P.M. Barometer uncorrected. Crown Glass.	3 o'clock, P.M. Att. Ther.	Dew Point at 9 A.M. deg. Fahr.	Diff. of Wet and Dry Bulb Thermometer.	External Thermometers. Fahrenheit. 9 A.M.	External Thermometers. Fahrenheit. 3 P.M.	External Thermometers. Self-registering. Lowest	External Thermometers. Self-registering. Highest	Rain in Inches. Read off at 9 A.M.	Direction of the Wind at 9 A.M.	REMARKS.
SEPTEMBER ○ W 1	30.068	30.060	64.4	30.038	30.030	66.6	59	07.1	59.7	66.3	52.7	72.8		NW	A.M. Fine—light haze. P.M. Fine—lt. clouds. Ev. Fine & moonlight.
T 2	29.896	29.888	63.7	29.816	29.808	65.4	57	06.5	60.2	65.5	51.3	67.7		E	Fine—light clouds throughout the day. Ev. Fine and moonlight.
F 3	29.744	29.736	65.7	29.666	29.658	67.2	58	06.8	65.3	66.5	54.7	69.8		SSE	A.M. Fine—light clouds and wind. P.M. Overcast—heavy shower. Evening, Heavy rain, with thunder and lightning.
S 4	29.546	29.540	63.0	29.732	29.724	61.3	57	06.3	54.7	50.3	52.7	73.4	.536	W var.	A.M. Lightly overcast—high wind with light rain. P.M. Continued rain. Evening, Fine and moonlight.
☉ 5	29.874	29.866	58.6	29.818	29.810	58.6	51	05.8	53.2	52.0	47.2	57.6	.402	S	A.M. Light haze and wind. P.M. Lightly overcast—slight rain. Evening, Fine and starlight.
M 6	29.762	29.754	56.7	29.744	29.736	57.3	49	04.7	52.5	57.6	42.8	56.3	.019	S	A.M. Cloudy—light fog. P.M. Fine—light clouds and breeze. Ev. Fine and moonlight.
T 7	29.800	29.794	58.4	29.626	29.618	56.6	50	06.1	55.7	56.6	45.8	58.7		S	A.M. Cloudy—light breeze—fog early. P.M. Overcast—light rain. Evening, Cloudy.
W 8	29.800	29.794	64.2	29.900	29.894	60.4	54	05.5	60.7	66.2	52.6	62.0	.183	W	Fine—light clouds and breeze throughout the day. Evening, Fine and moonlight.
T 9	30.076	30.068	59.0	30.064	30.056	61.7	55	04.5	59.3	65.7	56.2	68.3		E	Cloudy—lt. wind throughout the day. Evening, Fine and starlight.
F 10	30.066	30.058	62.2	30.058	30.050	64.2	59	04.9	63.8	68.2	59.2	67.4		WSW	A.M. Lightly cloudy—light breeze. P.M. Fine and cloudless. Evening, Fine and starlight.
S 11	30.122	30.114	62.2	30.080	30.072	64.6	60	05.0	59.8	72.8	57.2	69.4		W	A.M. Fine—light clouds—fog early. P.M. Fine—light clouds. Evening, Fine and starlight.
☉ 12	30.012	30.004	68.6	29.910	29.904	69.8	64	06.8	68.4	76.6	60.6	74.7		E	Fine & cloudless—lt. breeze throughout the day. Ev. Fine & starlight.
M 13	29.932	29.924	68.7	29.910	29.902	69.3	64	06.0	68.3	73.7	61.0	78.5		E	Ditto ditto. Ditto.
T 14	29.892	29.884	70.4	29.850	29.844	70.3	65	05.5	66.8	72.7	62.0	75.3		ENE	Fine—light clouds & breeze throughout the day. Ev. Fine & starlight.
● W 15	29.966	29.958	69.6	29.940	29.932	69.4	65	06.3	67.7	68.8	62.6	71.4		S	Fine—lt. clouds & breeze throughout the day. Ev. Cloudy—lt. shower.
T 16	29.910	29.902	69.5	29.890	29.882	68.6	62	05.6	65.2	67.0	60.4	73.0	.063	S	A.M. Cloudy—stiff breeze—light shower. P.M. Fine—light clouds and breeze. Evening, Fine and starlight.
F 17	30.036	30.028	66.9	30.004	29.996	65.3	57	05.8	58.3	61.8	50.6	69.6		W	Fine—light clouds and breeze throughout the day. Evening, Fine and starlight—light fog.
S 18	29.964	29.956	61.3	29.942	29.936	62.3	56	05.9	54.7	64.7	49.8	67.7		S	A.M. Lt. haze—lt. fog early. P.M. Thick haze. Ev. Fine & starlight.
☉ 19	30.070	30.062	62.8	30.066	30.058	62.7	54	06.0	60.5	66.8	50.7	66.2		ENE	Fine—nearly cloudless, with lt. breeze throughout the day. Ev. Cldy.
M 20	30.184	30.176	63.0	30.152	30.144	65.6	61	04.1	62.5	66.5	60.0	68.7		E	A.M. Lightly overcast—light breeze. P.M. Fine—light clouds and breeze. Evening, Overcast.
T 21	30.018	30.010	63.7	29.920	29.914	66.0	61	02.1	60.3	64.7	59.7	70.0		ENE	A.M. Overcast—stiff breeze. P.M. Fine—lt. clouds—stiff breeze. Evening, Overcast.
W 22	29.692	29.684	63.0	29.700	29.694	65.3	61	02.0	59.4	64.3	58.2	67.2	.087	SE	A.M. Cldy.—lt. brisk wind. P.M. Fine—lt. clds. Ev. Fine & starlight.
T 23	29.688	29.682	62.3	29.648	29.642	63.2	59	02.4	55.7	60.5	55.4	66.4	.602	S	A.M. Overcast—light steady rain—thunder early. P.M. Fine—light clouds and breeze. Evening, Overcast.
F 24	29.578	29.572	61.6	29.568	29.562	62.4	53	05.1	58.3	60.3	56.0	62.2	.366	SSE	A.M. Lightly overcast—rain during the night. P.M. Fine—light clouds and wind. Evening, Overcast—light rain.
S 25	29.468	29.462	61.0	29.514	29.506	62.4	57	05.1	57.5	61.3	53.6	63.3	.158	S	A.M. Cldy.—lt. showers & wind. P.M. Showery. Ev. Fine & starlight.
☉ 26	29.504	29.498	62.0	29.484	29.476	61.6	56	05.2	58.2	60.2	53.7	63.6	.080	SE	A.M. Fine—light clouds and breeze, with showers. P.M. Fine—lt. clouds. Ev. Overcast—lt. rain.
M 27	29.548	29.540	59.9	29.614	29.608	61.3	57	04.6	56.8	63.7	54.0	62.4	.327	W	Fine—light clouds and breeze throughout the day. Ev. Overcast—brisk wind.
T 28	29.404	29.398	60.4	29.348	29.342	61.4	58	04.2	58.2	63.3	56.5	64.7	.438	S	Overcast—light rain—high wind throughout the day—very high wind throughout the night. Ev. Cloudy—high wind.
W 29	29.252	29.248	63.4	29.362	29.354	62.8	59	06.1	61.2	62.8	58.0	66.8	.088	S	A.M. Cldy.—very h. wind, with showers, also very high throughout the night. P.M. Fine—lt. clds.—h. wind. Ev. Cldy—brisk wind.
○ T 30	29.248	29.242	61.5	29.264	29.258	62.8	58	04.0	58.7	62.3	56.0	64.4	.366	S var.	A.M. Overcast—light steady rain—high wind. P.M. Dark heavy clouds—high wind. Evening, Cloudy.
MEAN.	29.804	29.797	63.3	29.788	29.780	63.5	58	05.2	60.1	64.4	51.7	67.3	Sum. 3.715		Mean Barometer corrected .... 9 A.M. 3 P.M. F. 29.716 .. 29.699 C. 29.708 .. 29.690
OCTOBER F 1	29.478	29.472	59.6	29.516	29.508	60.8	56	02.8	55.7	58.8	53.6	64.3	.100	ENE	Overcast—light rain and fog throughout the day. Evening, early part, light rain, after part, fine and moonlight.
S 2	29.812	29.804	59.2	29.804	29.796	60.2	53	02.8	53.3	59.7	49.0	61.0	.313	SW	Fine—nearly cloudless—light breeze throughout the day. Evening, Fine and starlight—light fog.
☉ 3	29.832	29.824	57.0	29.810	29.804	58.0	57	03.9	52.5	56.9	47.7	60.8		N	A.M. Fine—lt. clouds & wind. P.M. Overcast—lt. rain. Ev. Overcast.
M 4	29.718	29.712	57.8	29.562	29.554	69.0	53	03.1	54.9	58.2	51.3	58.4	.125	N	A.M. Fine—light clouds and wind. P.M. Cloudy—light wind. Evening, Overcast—light rain.
T 5	29.160	29.156	58.0	29.050	29.046	58.4	54	04.7	53.2	57.7	51.7	60.5	.272	S	A.M. Fine—lt. clouds & wind, with showers—heavy rain during the night. P.M. Fine—lt. clouds & wind. Ev. Overcast—lt. rain.
W 6	28.848	28.844	57.2	28.866	28.858	58.3	53	04.7	52.3	58.3	49.0	58.8	.205	SSE	A.M. Cloudy—light wind with showers. P.M. Fine—light clouds and wind. Evening, Fine and moonlight.
T 7	29.040	29.036	55.9	29.070	29.064	57.2	52	04.7	53.3	57.0	48.6	59.7	.063	S	Fine—light clouds and wind throughout the day. Ev. Cloudy—lt. rain.
F 8	29.200	29.196	55.2	29.304	29.300	56.4	51	03.4	52.7	54.4	48.8	59.3	.012	S	A.M. Fine—light clouds—slight rain. P.M. Cloudy—slight rain. Evening, Overcast—slight rain.
S 9	29.778	29.770	53.8	29.830	29.824	55.7	50	03.2	50.7	55.6	48.5	58.2	.027	WSW	A.M. Ovct.—slight rain & wind. P.M. Cldy.—lt. rain. Ev. The same.
☉ 10	29.878	29.870	53.8	29.786	29.780	55.5	49	04.7	54.3	55.5	48.4	57.2		S	A.M. Fine—light clouds and wind. P.M. Overcast—light rain and wind. Evening, Overcast—continued rain.
M 11	29.660	29.652	57.0	29.626	29.618	57.3	52	03.7	53.8	58.2	52.7	58.7	.150	SSW	Fine—light clouds—brisk wind throughout the day. Half-past 4 P.M. rainbow. Evening, Overcast—steady rain.
T 12	29.254	29.248	55.0	29.356	29.350	55.8	52	04.4	52.7	53.2	49.3	60.0	.352	S	A.M. Fine—lt. clouds & wind—slight showers. P.M. Cloudy, with showers. Ev. Fine & starlight.
W 13	29.922	29.914	53.5	30.042	30.036	54.7	47	04.8	49.7	52.5	46.0	55.7	.186	W	A.M. Fine—lt. clouds & wind. P.M. Lightly overcast. Ev. Overcast—very slight rain.
○ T 14	29.860	29.852	55.0	29.838	29.830	57.3	53	03.7	58.3	60.6	49.8	59.8		S	A.M. Early part cloudy—after part fine—light clouds. P.M. Fine—light clouds. Evening, Overcast—slight rain.
F 15	29.550	29.546	57.2	29.632	29.626	58.0	53	04.8	56.4	57.8	54.2	63.7	.022	SW	A.M. Fine—lt. clouds & wind. P.M. Ovct.—slight rain. Ev. Fine and starlight.
S 16	29.474	29.468	53.9	29.372	29.366	55.4	50	03.0	51.8	57.8	46.0	60.2	.441	S	Overcast—lt. rain & wind throughout the day. Ev. Fine & starlight.
☉ 17	29.516	29.508	53.8	29.482	29.476	56.0	51	03.8	54.7	59.0	47.8	58.8	.033	SW var.	A.M. Overcast—high wind. P.M. Dark heavy clouds—high wind. Evening, Fine and starlight—high wind.
M 18	29.704	29.698	54.0	29.912	29.904	54.6	49	05.8	52.5	53.8	50.5	62.6		W	A.M. Fine—lt. clouds—high wind—high wind throughout the night. P.M. Fine—lt. clouds & wind—slight rain. Ev. Ovct.—heavy rain.
T 19	29.628	29.620	52.7	29.886	29.878	52.7	46	03.1	46.3	50.0	47.0	56.3	.427	W	Fine—lt. clds. & wind the whole day—rain early. Ev. Fine & starlight.
W 20	29.926	29.918	50.2	29.798	29.790	51.6	44	04.0	47.8	53.0	43.2	51.7		S	Fine—nearly cloudless—light wind throughout the day. Ev. Overcast—very slight rain—high wind.
T 21	29.896	29.888	49.3	30.068	30.060	49.8	42	04.4	42.7	46.8	40.7	55.0	.019	W	Fine & cloudless—lt. wind throughout the day. Ev. Fine & starlight.
F 22	30.170	30.162	46.0	30.032	30.024	48.7	36	04.0	41.8	48.8	37.7	49.0		S	A.M. Early part, light fog, after part fine—light clouds and wind. P.M. Fine—light clouds and wind. Ev. Fine and moonlight.
S 23	29.456	29.448	48.3	29.264	29.256	51.8	45	04.8	53.8	56.3	42.0	55.5		S	Cloudy—lt. rain & wind nearly the whole day. Ev. Cldy.—high wind.
☉ 24	28.944	28.940	51.2	28.970	28.966	52.2	47	03.5	49.3	52.5	48.6	58.3	.250	S var.	Overcast—h. wind throughout the day. Ev. Fine & moonlight—lt. fog.
M 25	29.098	29.094	49.2	29.176	29.170	50.8	46	02.5	44.2	51.7	44.0	55.6		S	Light fog and wind early, the rest of the day fine—light clouds. Evening, Fine and moonlight.
T 26	29.352	29.346	47.2	29.398	29.392	49.2	39	02.0	39.8	49.7	37.2	52.8		W	Cloudy—light wind and fog throughout the day. Ev. Overcast—light rain—high wind.
W 27	29.460	29.452	48.6	29.424	29.420	49.2	45	02.7	47.5	47.5	40.0	51.2	.066	N	Overcast—lt. rain—high wind throughout the day. Ev. Steady rain—high wind.
T 28	29.642	29.636	49.5	29.732	29.728	50.2	46	01.0	46.8	47.3	47.2	50.2	.930	N	Overcast—light rain—high wind throughout the day. Evening, Early part, cloudy, after part fine and moonlight.
F 29	29.848	29.842	48.7	29.836	29.828	49.3	45	02.6	46.7	48.7	44.7	49.6	.069	N	A.M. Fine—light clouds—brisk wind. P.M. Cloudy—slight rain. Evening, Cloudy—brisk wind.
● S 30	29.784	29.780	48.7	29.734	29.728	49.2	44	01.8	45.7	47.2	46.0	50.5	.058	N	Overcast—light rain—high wind throughout the day. Ev. The same.
☉ 31	29.838	29.832	49.8	29.866	29.858	50.8	47	02.0	49.3	51.2	46.0	50.5	.122	N	Ditto ditto. Ditto.
MEAN.	29.572	29.565	53.1	29.582	29.575	54.7	49	03.6	50.5	54.1	47.0	56.9	Sum. 4.142		Mean Barometer corrected .... 9 A.M. 3 P.M. F. 29.511 .. 29.517 C. 29.503 .. 29.509

METEOROLOGICAL JOURNAL FOR NOVEMBER AND DECEMBER, 1841.

1841.	9 o'clock, A.M.			3 o'clock, P.M.			Dew Point at 9 A.M., deg. Fahr.	Diff. of Wet and Dry Bulb Ther.	External Thermometers.				Rain in inches. Read off at 9 A.M.	Direction of the Wind at 9 A.M.	REMARKS.
	Barometer uncorrected.		Att. Ther.	Barometer uncorrected.		Att. Ther.			Fahrenheit.		Self-registering				
	Flint Glass.	Crown Glass.		Flint Glass.	Crown Glass.				9 A.M.	3 P.M.	Lowest	Highest			
NOVEMBER															
M 1	29.948	29.940	50.0	29.984	29.976	50.7	46	02.5	46.5	48.8	46.3	53.2	.175	W	Overcast—slight rain and wind throughout the day. Ev. Light fog.
T 2	30.238	30.232	49.7	30.242	30.236	50.7	45	02.3	47.2	50.3	46.2	50.3	.072	N	Overcast—light fog throughout the day. Evening, The like.
W 3	30.368	30.360	49.6	30.368	30.360	50.7	46	02.5	48.3	52.2	46.6	51.4		N	A.M. Thick fog. P.M. Overcast. Evening, Light fog.
T 4	30.424	30.416	50.0	30.386	30.378	50.7	45	02.1	47.3	48.4	46.2	53.5		E	Overcast—light brisk wind throughout the day. Ev. Cloudy—lt. fog.
F 5	30.400	30.394	49.2	30.398	30.392	50.0	45	02.8	47.0	49.4	46.0	50.0		SE	Cloudy—light wind throughout the day. Evening, Fine—light fog.
S 6	30.450	30.442	49.6	30.404	30.396	51.2	46	02.4	48.8	54.3	45.4	50.9		S	A.M. Overcast—light wind. P.M. Fine and cloudless. Ev. Fine and starlight—light fog.
☉ 7	30.436	30.430	49.8	30.402	30.396	51.0	46	02.2	46.5	51.5	44.4	55.6		S	A.M. Light fog—deposition—light wind. P.M. Lightly overcast—light wind. Ev. Fine and starlight—light fog.
M 8	30.370	30.362	49.2	30.338	30.330	50.7	46	01.8	46.3	49.6	43.3	52.8		S	A.M. Light fog & wind. P.M. Fine—nearly cloudless. Ev. Light fog.
T 9	30.328	30.320	48.3	30.266	30.258	49.7	44	03.0	44.3	47.3	42.6	51.7		S	A.M. Lightly overcast—light wind. P.M. Fine—light clouds and wind. Evening, Overcast—light fog.
W 10	30.180	30.172	49.0	30.112	30.104	50.3	45	03.8	50.3	52.0	44.6	51.7		W	Overcast—light wind throughout the day. Evening, The like.
T 11	30.018	30.010	50.2	30.000	29.994	51.4	46	02.9	50.3	53.3	48.7	53.8		S	A.M. Lightly overcast—lt. wind. P.M. Fine—lt. clds. Ev. Overcast.
F 12	29.584	29.578	50.3	29.520	29.514	51.3	47	01.6	50.8	49.7	45.2	55.5	.416	S	A.M. Dark broken clouds—light wind—very heavy rain early. P.M. Fine—lt. clouds and wind. Ev. Fine and starlight.
○ S 13	29.468	29.462	47.0	29.410	29.402	48.8	41	03.4	42.2	47.7	40.0	52.7		SW	A.M. Fine—light clouds and wind. P.M. Cloudy—slight rain. Evening, Overcast—light rain.
☉ 14	29.044	29.036	45.7	29.226	29.220	45.0	36	02.2	38.3	40.8	36.4	48.6	.258	WNW	A.M. Overcast—slight rain—snow early. P.M. Fine—light clouds—high wind. Evening, Fine and starlight.
M 15	29.486	29.480	40.6	29.348	29.342	41.3	32	02.3	34.3	38.3	32.6	42.5		SW	Light fog—sharp frost throughout the day. Ev. Ovct.—lt. fog—sharp frost.
T 16	29.454	29.448	39.3	29.522	29.514	40.0	32	02.9	33.4	35.5	32.8	39.3		W	Fine—light clouds and wind—sharp frost throughout the day. Evening, Starlight—light fog.
W 17	29.706	29.698	35.8	29.626	29.620	36.9	29	02.8	29.7	37.4	28.2	35.9		S	A.M. Fine—light fog—white frost. P.M. Fine—light clouds. Ev. Overcast—light fog.
T 18	29.280	29.274	36.9	29.490	29.482	39.0	33	00.7	34.3	37.3	30.3	38.3	.122	N	A.M. Overcast—sleet and snow—light wind. P.M. Fine—dark broken clouds. Evening, Overcast.
F 19	29.462	29.454	40.0	29.252	29.246	41.6	40	02.3	43.7	46.8	34.8	44.8	.063	SE	Overcast—lt. rain & wind throughout the day. Ev. Starlight—light fog.
S 20	29.366	29.358	41.3	29.210	29.204	43.2	37	01.8	39.5	48.8	36.8	48.4	.183	S	A.M. Thick fog—lt. wind. P.M. Overcast—heavy rain. Evening, Light rain.
☉ 21	29.376	29.370	43.9	29.310	29.302	47.2	41	01.6	45.7	51.7	40.0	50.8	.183	SSE	Overcast—light rain—high wind throughout the day. Ev. The same.
M 22	29.204	29.200	51.3	29.212	29.208	52.8	49	01.4	54.4	54.3	46.7	56.2	.166	S	A.M. Overcast—light rain and wind. P.M. Heavy rain—high wind. Evening, Fine and starlight.
T 23	29.694	29.688	47.9	29.668	29.660	48.4	43	02.2	41.3	46.8	39.8	57.4	.188	S	A.M. Fine—light clouds and wind. P.M. Overcast—light wind. Evening, Foggy.
W 24	29.916	29.908	45.2	29.930	29.922	45.8	38	01.7	38.0	44.3	37.6	48.2		S	Fine—light clouds throughout the day. Ev. Overcast—light fog.
T 25	29.800	29.792	43.0	29.828	29.820	43.6	38	02.2	38.3	42.3	37.3	45.6		NW	A.M. Thick fog—deposition—light wind. P.M. Fine—light clouds. Evening, Light fog.
F 26	29.904	29.896	41.2	29.838	29.830	41.3	35	01.6	33.2	41.0	32.7	43.6		NW	A.M. Thick fog—deposition—light wind. P.M. Light fog & wind. Evening, Overcast.
S 27	29.704	29.698	42.3	29.632	29.626	44.3	39	01.7	44.3	50.2	32.6	45.5		SE	Overcast—deposition—lt. wind throughout the day. Ev. Overcast—lt. rain.
◐ ☉ 28	29.666	29.660	46.2	29.592	29.586	47.7	43	01.7	45.3	49.7	44.6	52.2	.111	S	A.M. Fine—light clouds and wind, with showers. P.M. Fine—light clouds—Ev. Overcast—light rain—high wind.
M 29	29.236	29.232	50.0	29.106	29.100	51.3	48	01.6	50.4	53.0	45.2	54.2	.575	S	Overcast—very high wind, with occasional rain throughout the day, as also throughout the night.
T 30	28.952	28.948	53.3	29.008	29.002	53.3	52	02.5	53.8	53.4	51.2	58.6	.338	SSE	Overcast—very high wind, with occasional rain throughout the day, as also the night.
MEAN.	29.782	29.775	46.2	29.754	29.747	47.3	42	02.2	43.9	47.5	40.8	49.8	Sum. 2.850		Mean Barometer corrected .... 9 A.M. F. 29.739, C. 29.731 .. 3 P.M. F. 29.708, C. 29.700
DECEMBER															
W 1	29.396	29.392	50.8	29.338	29.332	51.4	48	01.5	48.7	51.0	47.6	55.8	.055	SE	A.M. Lt. fog & wind. P.M. Overcast—lt. rain & wind. Ev. Overcast.
T 2	29.486	29.478	50.5	29.450	29.444	51.4	47	02.6	49.3	51.0	47.3	52.4	.033	S	A.M. Fine lt. clds. and wind. P.M. Cloudy—lt. wind. Ev. Overcast.
F 3	28.954	28.950	50.7	29.066	29.060	51.7	48	02.7	51.2	50.4	49.0	53.3	.039	E	A.M. Dk. heavy clds. with shrs.—h. wind—h. wind, with rain all night. P.M. Fine—lt. clds.—high wind. Ev. Fine and starlight—lt. wind.
S 4	29.272	29.266	48.6	29.392	29.384	49.0	45	02.4	48.0	48.3	45.4	53.4	.172	S	A.M. Fine—light clouds and wind—high wind throughout the night. P.M. Light rain and wind. Ev. Light fog.
☉ 5	29.960	29.952	47.3	30.042	30.038	48.0	40	03.3	44.0	47.5	43.4	50.6	.161	W	A.M. Fine—lt. clds. & wind. P.M. Lightly overct. Ev. Overcast—lt. fog.
M 6	29.776	29.768	48.0	29.646	29.640	49.5	45	01.7	50.2	48.4	43.5	51.4	.091	S	Overcast—light rain and wind nearly throughout the day. Ev. Fine and starlight.
T 7	29.916	29.908	46.6	29.888	29.880	47.6	43	02.6	43.0	48.3	40.6	53.0	.222	S	Lightly overcast—lt. wind throughout the day. Ev. Overcast—lt. rain.
W 8	29.488	29.480	48.7	29.390	29.384	49.9	47	01.6	50.7	51.7	43.2	51.8	.119	S	A.M. Overcast—very light rain and wind. P.M. Fine light clouds. Ev. Fine and starlight.
T 9	29.916	29.908	46.7	29.914	29.908	46.6	40	02.7	41.3	43.8	40.8	54.4		W	A.M. Fine—light clds. and wind. P.M. Hazy. Ev. Overcast—lt. rain.
F 10	29.386	29.380	48.8	29.380	29.372	50.0	46	01.8	50.7	48.8	41.6	52.2	.116	S	A.M. Overcast—light rain and wind. P.M. Fine—light clouds and wind. Ev. Fine and starlight.
S 11	29.916	29.908	45.6	29.920	29.912	46.0	40	02.8	40.8	45.3	40.0	54.8	.083	W	Fine—light clouds and wind throughout the day. Ev. Overcast.
○ ☉ 12	29.660	29.652	45.5	29.544	29.540	47.0	43	02.1	47.7	51.0	41.0	49.3	.077	S	Overcast—light rain and wind throughout the day. Ev. The like.
M 13	29.366	29.358	49.0	*omitted*	*omitted*	*omitt.*	46	01.8	51.0	*omitt.*	48.4	52.3	.213	S	A.M. Dark heavy clouds—high wind—high wind and rain throughout the night. P.M. Overcast. Ev. Fine and starlight.
T 14	29.540	29.534	47.2	29.822	29.816	46.3	40	02.8	42.2	41.3	42.2	53.2	.061	W	A.M. Cloudy—brisk wind—light rain. P.M. Cloudy—light wind. Ev. Fine and starlight.
W 15	29.908	29.900	42.6	29.710	29.702	44.8	39	02.8	42.8	47.8	35.2	43.7		S	A.M. Cldy.—brisk wind—lt. rain. P.M. Overct.—h. wind. Ev. The like.
T 16	29.400	29.394	45.2	29.280	29.276	45.7	42	02.4	42.3	43.5	41.6	50.3	.063	S	Fine—lt. clouds and wind throughout the day. Ev. Fine and starlight.
F 17	29.494	29.488	42.7	29.566	29.560	43.0	38	02.3	35.3	38.5	35.4	45.7		W	A.M. Fine—light clouds throughout the day—fog early part. Evening, Starlight—light fog.
S 18	29.586	29.578	38.8	29.494	29.486	38.5	34	01.6	31.3	35.2	31.2	38.8		S	Fine—light fog—white frost throughout the day. Ev. Fine and starlight—sharp frost.
☉ 19	29.252	29.246	34.8	29.174	29.170	36.0	28	00.8	31.4	34.4	29.9	35.7		N	Cldy.—lt. wind—sharp frost throughout the day. Ev. Lt. fog—sharp frost.
M 20	29.226	29.220	35.0	29.290	29.282	35.7	30	*frozen*	32.7	34.5	31.6	35.5		N	A.M. Fine—light clouds and wind—sharp frost. P.M. Hazy—sharp frost. Ev. Light fog—sharp frost.
T 21	29.626	29.620	37.0	29.656	29.650	36.6	32	00.9	32.3	34.3	32.8	36.2		NW	Fine—light clouds and wind throughout the day—early part foggy. Ev. Fine and moonlight.
W 22	29.790	29.784	39.8	29.814	29.806	38.8	33	01.0	32 8	36.8	32.6	37.0		W	Fine—light clouds and wind throughout the day. Ev. Overcast.
T 23	29.860	29.852	43.0	29.782	29.776	43.3	38	00.5	39.7	44.8	33.3	40.8	.014	S	A.M. Overcast—light wind—very slight rain. P.M. Overcast—deposition. Ev. Fine and moonlight.
F 24	30.050	30.044	41.9	29.984	29.976	43.2	40	01.1	39.3	47.3	36.9	47.4	.060	S	A.M. Light fog and wind. P.M. Overcast—slight rain. Ev. The like.
S 25	29.768	29.760	45.7	29.646	29.642	46.0	42	01.7	44.3	44.6	39.6	50.4	.183	S	Overcast—light rain and wind throughout the day. Ev. Fine and moonlight.
☉ 26	29.794	29.788	41.0	29.888	29.884	41.2	35	01.0	35.8	38.6	33.4	46.0	.044	N	Overcast—light fog throughout the day. Ev. Fine and moonlight—light fog.
M 27	30.132	30.124	39.2	30.130	30.122	39.0	33	01.3	31.7	35.5	31.4	40.2		SW	Light fog—sharp frost nearly the whole of the day. Ev. Cloudy—thaw.
◐ T 28	30.088	30.080	39.0	30.092	30.084	40.3	35	01.6	38.8	43.2	31.5	40.0	.025	W	A.M. Light fog—deposition—light wind. P.M. Cloudy—light wind. Ev. Overcast—deposition.
W 29	30.106	30.100	41.8	30.070	30.062	42.8	39	01.4	43.4	45.8	39.3	45.2		W	A.M. Lt. fog—deposition. P.M. Cldy.—lt. rain. Ev. Overcast—lt. rain.
T 30	30.126	30.120	42.9	30.154	30.148	43.7	38	01.8	38.8	42.2	39.0	46.8	.038	NE	A.M. Cloudy—light wind. P.M. Fine—light clouds and wind. Ev. Cloudy—sharp frost.
F 31	30.262	30.254	41.7	30.226	30.218	42.3	35	01.0	35.0	40.7	35.0	43.2		E	Fine—light clouds and wind throughout the day—light fog early. Ev. Moonlight—lightly cloudy.
MEAN.	29.694	29.687	44.1	29.692	29.685	44.5	39	01.9	41.5	43.8	38.8	47.1	Sum. 1.869		Mean Barometer corrected .... 9 A.M. F. 29.657, C. 29.649 .. 3 P.M. F. 29.654, C. 92 646

PHILOSOPHICAL TRANSACTIONS.

VIII. *Sixth Letter on Voltaic Combinations. Addressed to* MICHAEL FARADAY, *Esq., D.C.L. F.R.S., Fullerian Prof. Chem. Royal Institution, &c. &c. &c.*

By J. FREDERIC DANIELL, *Esq., For. Sec. R.S., Prof. Chem. in King's College, London.*

Received April 22,—Read April 28, 1842.

MY DEAR FARADAY,

I MUST beg permission to address you once more upon the subject of Voltaic Combinations. To this I am prompted by several considerations.

In the first place, the beautiful law of OHM, and the simple expression which he has given of the electromotive force and resistances of a voltaic circuit, enable me to review with advantage, and to correct, many of the conclusions which I had derived from former experiments; and have suggested additional experiments, the results of which will tend, I trust, to remove some obscurities and ambiguities which were left in my former communications.

2nd. By following out these principles I shall be enabled to offer some practical remarks upon the different forms of voltaic batteries which have been brought forward to assist the speculations of the active inquirers, who, in the present day, are so eagerly engaged in applying the voltaic forces to the service of the arts.

3rd. I wish most particularly to explain more fully the principles of the cylindrical arrangements of the battery which I have introduced, and which appear to me to have been greatly misunderstood.

I am desirous, however, that you should understand that I do not present the following observations for the purpose of testing the law in question, or of determining constants connected with the formula, for that could only be satisfactorily effected by experiments of a much more delicate and accurate nature than those to which I shall have to refer; but with a view to show how generally the law applies, even to the practical results of operations carried on upon, what might be called, a manufacturing scale, in which disturbing influences are numerous, and in a great measure uncontrolable.

Professor OHM has adopted (I believe that you will concur with me in thinking,

unfortunately) the contact theory of the electromotive force ; and although his *formula* is easily adapted to either of the two rival views, it is perhaps necessary, in selecting the chemical theory, that I should define the exact meaning which I attach to his symbols, and explain the expansions which I think it necessary to introduce. The formula, you will remember, is

$$\frac{E}{R+r}=A,$$

where E represents the electromotive force (so called) in the cell: R the resistances in the cell: r the amount of exterior resistances: A the effective force, measured by the work performed. Now according to the chemical view, E must be the balance of several active forces in the cell.

1st. The superior affinity of the *generating* plate for the *anion*, of the electrolyte, which we will designate by B.

2nd. The inferior affinity of the *conducting* plate for the same *anion*, which we will call b.

3rd. The affinity of the *cation*, disengaged from the electrolyte and accumulated upon the conducting plate for the *anion*, this we will call e': these two last tend to produce polarization, as it is not very appropriately called, and a current in the opposite direction to B ; therefore

$$E=B-(b+e'), \text{ or}$$
$$E=B-b-e'.$$

R, the resistance in the cell, varies *directly* as the thickness of the electrolyte (or the distance between the generating and conducting plates), D, and inversely as the area of the section of the electrolyte, S ; therefore

$$R=\frac{D}{S}*.$$

r represents all the exterior resistances, whether metallic or electrolytic. In the metallic parts of the circuit, it will be *inversely* as the area of the section (*i. e.* the square of the diameter) of the wire s, and directly as the length l, or distance through which the current passes. In electrolytic work this metallic resistance may generally be disregarded ; the lengths of the connecting wires being insignificant with regard to the resistance of the electrolyte. This latter will be inversely as the area of the section of the electrolyte, s', and *directly* as the distance d between the electrodes: therefore

$$r=\frac{l}{s}+\frac{d}{s'}.$$

But we must now inquire particularly what it is we mean by the section of the electrolyte. The limits of the section of the metallic conductor are strict and easily

* The resistance of each liquid is specific, and depends upon the nature of the liquid, the degree of saturation (if a solution), and the temperature ; these circumstances remaining constant, it also is constant, and is so considered in this review of the formula.

determined; but, taking into consideration the diffusive nature of the electrolytic force, and the wide spread of that polarization of the particles of an electrolyte which we have traced upon a former occasion to the back surface of a conducting plate opposed to a mere point of generating metal*, it is more difficult to define the limits of its action so as to satisfy the conditions of the *formula*.

In a cell composed of a plate of generating metal with a conducting plate of equal dimensions, the interposed electrolyte only wetting the opposite faces of the two metals, the area of the section of the electrolyte will clearly be equal to the area of the acting surface of the conducting plate. In case the two metals should be immersed in a trough, in such a manner as to allow of the electrolyte being in contact with both sides of the plates, it is also probable that the action of the back surfaces might be disregarded without danger of material error in our calculations, although we know in fact that they would not be wholly passive. Up to this point, therefore, there is no difficulty in the application of OHM's formula.

But how are we to determine the area of the section of the electrolyte, when the surfaces of the generating and conducting plates are not equal? as, for instance, in the case of a rod of zinc placed within a cylinder of copper. Is it referrible solely to the surface of the conducting plate? Or is it limited by the mean of the surfaces of the two plates? The experimental investigation of this point, although the final result is extremely simple, has cost me much labour. The apparently unlimited spread or radiation of the force from a point of generating metal over an indefinitely large surface of conducting metal, strongly suggested the first conclusion. This was moreover confirmed by the following consideration, viz. if we take the mean section of the electrolyte as determined by the mean of the surfaces of the two metallic plates between which it is included, it is clear that the result ought to be the same, whether the generating or conducting metal be the larger of the two. A rod of copper placed within a cylinder of zinc, ought to circulate the same amount of force as a rod of zinc placed within a cylinder of copper; the dimensions in both cases being respectively the same.

Now the results of a vast number of experiments, some of which I have already submitted to you†, seemed to prove that, so far from this being the case, the amount of force is reduced one-half when the lines of force are made to converge from a large generating surface towards a small conducting one; instead of diverging in the contrary arrangement, from a small generator to a large conductor.

These experiments I have again repeated, and when I made use of sulphate of copper in dilute sulphuric acid as the electrolyte, with the same general results.

The impossibility of reconciling this with the law, and the necessity of determining a point of such fundamental importance, together with a certain degree of unsteadiness of action in the experiments, induced me, at length, to change the electrolyte for one which would be less liable to alter its condition during the progress of the

* Philosophical Transactions, 1838, Part I. p. 54. † Ibid., pp. 47, 49, 53.

observations. The arrangement which I adopted was that of hollow cylinders of amalgamated zinc with platinum wire, and wire of amalgamated zinc with platinum cylinders, all of equal heights ; and the electrolyte in contact with the zinc consisted of standard dilute sulphuric acid, separated by a porous tube from strong nitric acid in contact with the platinum. A Breguet's thermometer, adapted to the purposes of a galvanometer*, was selected as a measure of the effects. The following Table exhibits the results :—

Table I.

Diameter of Zinc.	Diameter of Platinum.	Degrees of Galvanometer.
inches.		
$2\frac{3}{4}$	wire	274° Mean of three observations.
wire	$2\frac{3}{4}$	255 Mean of three observations.
wire	$1\frac{1}{3}$	279
$1\frac{1}{3}$	wire	273
		270 Mean.

The needle always returned after each experiment to the point from which it started. There can be no difficulty in taking these results as sensibly equal ; and it is therefore evident that a wire of platinum placed within a cylinder of zinc, established a current of exactly the same force, as a wire of zinc placed within a cylinder of platinum of equal diameter. Hence we may conclude that the area of the efficient section of the electrolyte is the mean of the opposed faces of the metal plates.

But how shall we account for the contrary results with sulphate of copper as the electrolyte, which were carefully made and greatly varied, but which always gave a consistent result of about one-half the force when the conducting was very small in proportion to the generating surface ?

By substituting acid sulphate of copper for nitric acid in the arrangement just described, and carefully attending to the progress of the experiment, the explanation became obvious.

When the platinum wire was placed in the porous tube in the centre of the zinc cylinder, upon first connection with the calorific galvanometer, the needle advanced to 83° ; but almost immediately began to return till it reached 28°, at which point it remained stationary. When the wire was withdrawn it was found covered with copper in a spongy or pulverulent form. It was wiped and replaced, and the needle advanced to 85°, but immediately began to retrograde and fell again to 28°. This process was repeated many times, and always with the same result. If, while the galvanometer was at its highest point, the wire was moved about and the liquid kept in a state of agitation, the needle remained steady for a longer time ; but when the wire was left at rest, the needle always receded.

* Philosophical Transactions, 1838, p. 42. This instrument is not absolutely to be depended upon when the power is high and the differences to be measured great, on account of the differences in its rates of cooling.

When, on the contrary, a zinc wire was placed in the porous tube in the centre of the platinum cylinder, charged with the sulphate of copper, the needle advanced to 96° upon an average of three experiments, and then remained quite steady. In this case, the precipitated copper was equally diffused over the surface of the platinum, and constituted a compact layer firmly attached to the plate. There can be no doubt that it is this difference in the state of the precipitated metal which gave rise to the difference in the results of the two arrangements. In the last case, the electrolysis of the liquid was carried on without the disengagement of any element tending materially to produce an opposing current; while in the first, the spongy state of the copper retained the liquid within its pores; which, after the precipitation of all the sulphate of copper which it contained, generated hydrogen, which was equally entangled in it, and produced a strong opposition to the current. The amount of this opposition is definite, and of nearly half the force of the principal current; and hence I was led to the erroneous conclusion regarding the relative sizes of the generating and conducting plates. Taking the measure of the force at the first moment of making the contacts, the results sufficiently confirm the conclusion drawn from the experiments with the nitric acid.

I once more tested the hypothesis, that it is the mean section of the electrolyte which regulates the current, and that it is indifferent whether the conducting or the generating metal be the larger of the two plates, by measuring the chemical results produced. For this purpose I weighed the amalgamated zinc cylinders and rods before and after the experiment, and ascertained the consumption of metal for intervals of half an hour, during which the circuits were closed. The conducting metal was copper, and the rods half an inch in diameter. The electrolyte was sulphate of copper and dilute sulphuric acid, and was kept agitated during the immersion of the copper rods. The results are set down in the following Table:—

Table II.

Diameter of Zinc.	Diameter of Copper.	Loss of Zinc in thirty minutes.
inches.	inches.	grs.
$\frac{1}{2}$	$2\frac{3}{4}$	30
$2\frac{3}{4}$	$\frac{1}{2}$	30
$\frac{1}{2}$	$5\frac{1}{2}$	29·7
$5\frac{1}{2}$	$\frac{1}{2}$	30

These results perfectly accord with the preceding.

From the consideration of the foregoing experiments, we are led to another important relation of the generating and conducting metals in these cylindrical arrangements, to understand which, it must be borne in mind that the surfaces of cylinders, of equal heights, are directly proportioned to their radii.

Let us therefore imagine an indefinitely small rod of a generating metal placed in the axis of a cylinder of conducting metal of a given diameter, filled with an electrolyte; upon making contact of the two metals, a current would be established of a definite

amount. The area of the mean section of the electrolyte would be the area of a cylinder placed half way between the cylinder and its axis, or half that of the cylinder; and it would be the same whether the generating or the conducting metal were the exterior of the two.

Now the amount of the current ought to be the same whatever might be the diameter of the exterior cylinder, for the resistance occasioned by increasing the depth of the electrolyte, that is to say, by increasing the radius of the cylinder, is exactly counterbalanced by the increased conducting power conferred by the increased area of the section of the electrolyte, and *vice versâ*. The results of the experiments confirm this conclusion; for upon reference to Table I. it will be seen that cylinders of $1\frac{1}{3}$ inch and $2\frac{3}{4}$ inches diameter produced, under like circumstances, the same amount of current; and from Table II. we learn that cylinders of $2\frac{3}{4}$ inches and $5\frac{1}{2}$ inches diameter had equal influences.

You may perhaps remember, that in my former communications, from some experiments upon this point*, I had obtained some anomalous results which occasioned me considerable perplexity, but I have since multiplied observations sufficiently to place the confirmation of the law beyond a doubt.

Amongst others, I repeated the experiments with the large battery of ten cells of four inches diameter, in comparison with ten of $3\frac{1}{2}$ inches, and found the results sensibly the same. The origin of the error in my former observations I have been unable to detect; but it is probably to be ascribed to some fault in the connections of the cells.

The advantages of the concentric cylindrical arrangement of the elements of a voltaic circuit are very considerable; both in the scientific analysis of its complex actions and in its practical applications. The absolute restriction of the influence of the metallic plates to one side respectively, and the known definite relations of their surfaces and diameters, render the necessary calculations for the former obvious and easy; while for the latter, the reduction of the size of the generating metal, and the large quantity of the electrolyte which it admits of, give facilities for the maintenance of an energetic and constant current of force which no other arrangement can supply with equal effect.

I have already observed† that the position of the rod within the cylinder is immaterial to the effects, and it is obvious, that wherever placed, their mean distances, and consequently the mean section of the interposed electrolyte, must be the same.

A zinc rod of half an inch in diameter, placed in the axis of a copper cylinder $3\frac{1}{4}$ inches diameter, produces a certain effect, which is scarcely augmented in an appreciable degree by a second, or even a third similar rod placed in contact with it: the results of experiment were as follows:—

1 rod = 2·2
2 rods = 2·4
3 rods = 2·5

* Philosophical Transactions, 1839, p. 90.

† Ibid. 1838, pp. 44, 49.

Each rod separately would have been capable, in its position, of producing the full effect of one; but each was screened by the two others from the full aspect of the conducting cylinder, and but a slight advantage was gained from the combination by a slight increase of the section of the electrolyte, uncompensated by any increase of distance.

I anticipated that, if each rod were removed as nearly as possible to the sides of the cylinder, so as to be equidistant from the other two, the screening influence could not take place to the same extent, and that a greatly-increased effect would be produced. A glance at the annexed diagram will explain the difference of the two arrangements; fig. 1. representing a section of the first, and fig. 2. of the second.

Fig. 1.

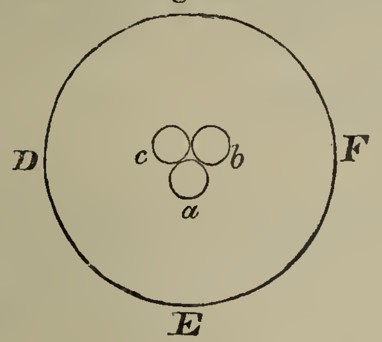
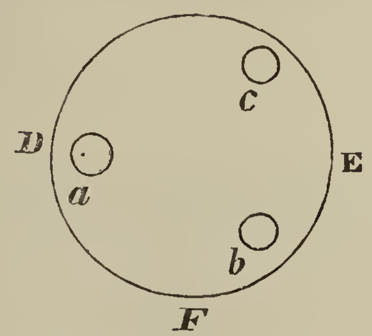


Fig. 2.



Upon making the experiment, as in fig. 2, with the rods and cylinder of the last experiment, the result was increased to 3·1.

I also tested the conclusion with the large battery of ten cells of four inches diameter, and obtained from single rods $10\frac{1}{2}$ cubic inches of mixed gases per minute, and from two rods placed as near to the sides of the cylinders as possible, fourteen cubic inches per minute.

The law of the exact compensation of the greater resistance arising from the increased thickness of the electrolyte, by the extension of the area of its mean section, is of course only mathematically correct where the interior wire is infinitely small, but practically the half-inch rods bear so small a proportion to the cylinders which I have been in the habit of employing, that the results are not materially affected by their dimensions. When, however, the interior cylinders are enlarged, the thickness of the electrolyte is decreased, and the area of its section increased at the same time, and the circulating force rapidly augments. The results are easily submitted to calculation.

Fig. 3.

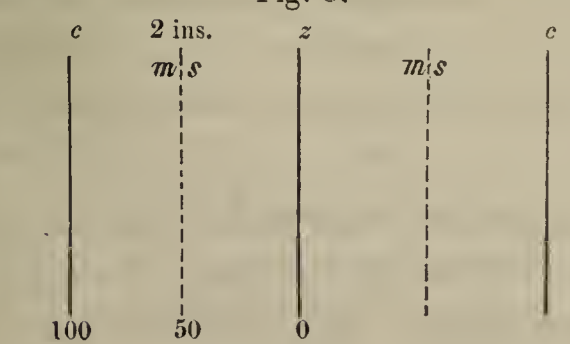
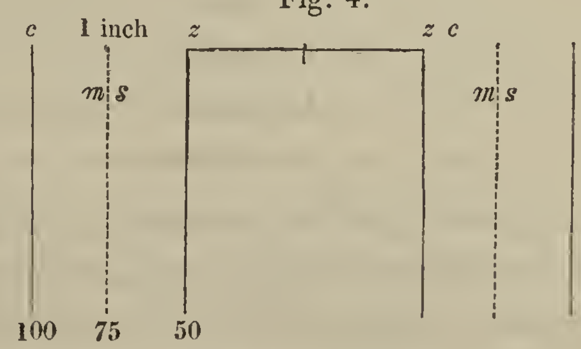


Fig. 4.



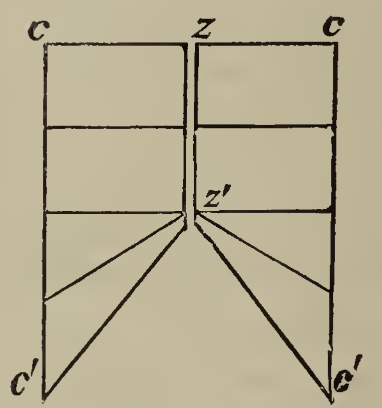
Let *c c*, fig. 3, represent a section of a copper cylinder four inches in diameter, and

z an infinitely small zinc rod in the axis. Let the area of the copper-plate be 100, the area of the mean section of the electrolyte ($m\ s$) will be $= 50$. The distance of c from z, or the thickness of the electrolyte, will be 2 inches. Let the rod z be replaced by a cylinder of zinc $z\ z$, two inches in diameter, fig. 4. The mean section will be increased to 75, and the thickness of the electrolyte will be decreased to 1 inch.

The force would, therefore, be increased in the proportion of 50 : 75 for the first, and of 1 : 2 for the second: consequently, compounding the proportions, the force circulating in the first arrangement would be to that in the second as 1 : 3.

In the preceding observations the cylinders and rods have been taken of equal heights; when one is shorter than the other, it will be obvious, from a little consideration, that the decrease of length is equivalent to an increase of distance between the two.

Fig. 5.



Let $c\ c\ c'\ c'$ represent a section of a copper cylinder, and $z\ z'$ a zinc rod of half its height; in any action which may take place from the point of the rod z' to the lower half of the cylinder c', the distance between the metals $z'\ c'$, or virtual thickness of the electrolyte being greatly augmented, the influence of the lower half will be proportionally diminished.

In some experiments which were carefully made with the calorific galvanometer, an amalgamated zinc rod was successively immersed in the electrolyte in a copper cylinder $3\frac{1}{2}$ inches high to the following depths, and with the results set down in the Table:—

Length of Zinc.	Degrees of galvanometer.
$\frac{1}{4}$ inch	7
$\frac{1}{2}$ inch	19
$\frac{3}{4}$ inch	35
1 inch	49
$1\frac{1}{4}$ inch	67
$3\frac{1}{2}$ inches	97

In a copper cylinder, twenty-one inches in height, charged with dilute sulphuric acid and sulphate of copper, an amalgamated zinc rod lost 51·5 grains in five minutes; a rod of half the length lost in the same time 26·1 grains. In a similar cylinder, six inches in height, charged in a similar manner, a zinc rod of equal length lost 12

grains; a rod of half the length lost 6·6 grains in the same time. The results, therefore, of each cylinder may be taken as directly proportioned to the lengths of the rods immersed in them.

Let us now turn from the consideration of simple circuits, and examine the law of a series, or of compound circuits. OHM's formula for these is

$$\frac{n\mathrm{E}}{n\mathrm{R}+r}=\mathrm{A},$$

in which n represents the number of the series.

Now so long as the external resistance (r) interposed in the circuit is merely metallic, the expression accords strictly with the results of experiment; and by doubling the number of cells at the same time that we double the efficient surface in each cell, we obtain an effect exactly double: thus by the formula

$$2\left(\frac{n\mathrm{E}}{n\mathrm{R}+r}\right)=\frac{2n\mathrm{E}}{\frac{2n\mathrm{R}}{2}+r}=\frac{2n\mathrm{E}}{n\mathrm{R}+r};$$

since in doubling the surface in each cell, *cæteris paribus,* we halve the resistance.

When, however, a voltameter or other chemical resistance is interposed in a circuit, OHM's formula will not hold, unless the opposite electromotive force which arises from the decomposition of the electrolyte, and consequent accumulation of ions upon the electrodes of the decomposing cell, be taken into consideration. This is of the same nature as the contrary electromotive force in the cell which we have already pointed out and designated by e' in the formula $\mathrm{E}=(\mathrm{B}-b-e')$. Professor WHEATSTONE, from a series of experiments made conjointly with myself, with my battery, and published in my fifth letter to you, inferred that, if this contrary electromotive force be assumed to be constant and be represented by e and introduced into the formula, thus

$$\frac{\mathrm{E}-e}{\mathrm{R}-r}=\mathrm{A},$$

tables might be calculated which would represent, approximatively, the quantity of decomposition for any number of cells of a given battery, while the results obtained by regarding the voltameter merely as a resistance, are, it is evident, widely at variance with the truth. Professor WHEATSTONE devised the following simple means to determine, on this supposition, the values of this contrary electromotive force, and of the added resistance, including that of the voltameter, without having recourse to any other measuring instrument than the voltameter itself. To obtain the value of the contrary electromotive force, he compared two experiments in which the resistances remained the same, while the sum of the electromotive forces alone varied. It is obvious that, if there existed no contrary electromotive force, the measured effect in the two cases should be simply as the number of elements in the series employed. A battery of five single cells should have half the power of a battery of ten double cells; but instead of this the effects measured by the voltameter were as 6 : 20.

$$\frac{10\,\mathrm{E}-e}{\frac{10}{2}\mathrm{R}+r}:\frac{5\,\mathrm{E}-e}{5\,\mathrm{R}+r}::20:6,\ \text{whence}\ e=2{\cdot}857\,\mathrm{E}.\quad\ldots\quad(\alpha.)$$

The value of r in the formula, i. e. the resistance which the voltameter and connecting wires add to the circuit, will be ascertained in the following manner. The comparison was made with two batteries, one single and the other double, of ten cells each; the sum of the electromotive forces, therefore, remained the same, while the resistances only varied:

$$\frac{10\,\mathrm{E}-e}{10\,\mathrm{R}+r} : \frac{10\,\mathrm{E}-e}{\frac{10\,\mathrm{R}}{2}+r} :: 12{\cdot}5 : 20, \text{ whence } r = 3{\cdot}333\ \mathrm{R}. \quad . \quad . \quad . \qquad (\beta.)$$

Substituting the values thus found in the general formula $\frac{n\,\mathrm{E}-e}{n\,\mathrm{R}+r}$, he obtained the following results:—

Number of cells	3	4	5	10	15	20
Quantity of gas calculated .	$\frac{5}{8}$	$3\frac{3}{5}$	6	$12\frac{18}{25}$	$15\frac{21}{25}$	$17\frac{13}{25}$ cubic inches.
Quantity of gas observed . .	$1\frac{1}{8}$	$3\frac{7}{8}$	6	$12\frac{1}{2}$	$15\frac{3}{4}$	$17\frac{1}{2}$ cubic inches.

The existence of such a contrary electromotive force, and its great energy, are amply attested by connecting the platinum plates of a voltameter, which has been some time in action, with a galvanometer; but I purpose to show the *general agreement* of the amended formula with the results of various and most trying combinations of different batteries, many of which were obtained without the slightest suspicion of the conclusions which might be derived from them. I say *general agreement*, for the extremely complicated nature of the actions to be measured, subjected as they were to the necessarily variable influence of circumstances affecting them, the large scale upon which the experiments were carried on, and the roughness and imperfection of the modes of measurement, would necessarily preclude the expectation of absolute accuracy. The remainder of the experiments, already published in my fifth letter, made with circuits which contained an equal number in series, but in which they were combined as double, treble, quadruple cells, &c., do not furnish results according with theory so well as might have been expected; they were therefore repeated with great care, and combined in various ways. The details of these experiments will presently appear. The first series was made with a constant battery composed of copper cylinders, six inches high, $3\frac{1}{2}$ inches in diameter, charged in the usual way with dilute sulphuric acid and sulphate of copper.

The first thing to be done was to determine the value of e in these combinations in the modified formula, by comparing the results of two arrangements in which the sums of the electromotive forces might vary, while the resistance remained the same. Thus

Cubic inches.

in five single cells, $\frac{5\,\mathrm{E}-e}{5\,\mathrm{R}+r} = 11{\cdot}25$ by experiment;

in ten double cells, $\frac{10\,\mathrm{E}-e}{\frac{10\,\mathrm{R}}{2}+r} = 33{\cdot}7$ by experiment;

therefore $5\,\mathrm{E}-e : 10\,\mathrm{E}-e :: 11{\cdot}25 : 33{\cdot}7$, or $e = 2{\cdot}49\ \mathrm{E}$.

To determine the value of r in the formula, we might compare, in a similar manner, as pointed out by Professor Wheatstone, the results of two arrangements, in which the electromotive forces being equal, the resistances in the cells alone should vary. As, however, from the complicated nature of the arrangements, and the variability of different influential circumstances to which I have before alluded, I found it impossible to obtain two perfectly unexceptionable results for the comparison, I thought it allowable to take the mean of several; and from this I found that, with a voltameter whose platinum plates are three inches in length by one inch in width, a quarter of an inch apart, and charged with the standard dilute sulphuric acid, (sp. gr. 1·126), $r = 0·541$ R in a constant battery of the dimensions just described.

Now if a single cell of such a battery be taken and the circuits closed by a short thick wire, and the zinc rod forming the generating plate of the arrangement be weighed at intervals of five minutes, it will be found to lose 11·26 grs. for every such interval. This is a measure of the effective force of the circuit; and its equivalent in mixed gases is 25 cubic inches. This will be taken as the unit of work in the Table that follows, i. e. $\left(\frac{E}{R} = 1\right)$, and the calculated results for the different combinations will, in the third and fourth columns, be represented in fractions of this unit.

It is evident, that the amount of zinc, dissolved in such a single circuit, furnishes a measure of the maximum work that any number of such cells, combined in a single series, would be capable of performing; for $\frac{E}{R} = A$, and $\frac{nE}{nR + r}$ can never be greater than $\frac{E}{R}$, however great the value of n may be, so long as r has a positive value. In other words, however great the number of cells in a series, it is impossible, so long as any external resistance is interposed, that the result should be greater than that of a single cell in which no exterior resistance is opposed; although when r is very small when compared with n R, the results may be virtually equal.

If unity be taken to represent the maximum work that *any* single circuit can produce, then E will be represented by 1, and R also by 1, and

$$\frac{E}{R} = 1.$$

It is evident that in an effective circuit R can never equal E, but for the convenience of calculation it may be assumed to be so; and as all the quantities in the numerator are compared with E, and all in the denominator with R, the relative proportions will be exact. Taking the formula

$$\frac{nE - e}{nR + r} = A.$$

If $E = 1$ and $R = 1$, then $e = 2·49$, $r = 0·541$. Substituting different numerical values for n, we obtain for

			Calculation. Cubic inches.	Experiment. Cubic inches.
4 single cells,	$\frac{4-2{\cdot}49}{4+0{\cdot}541}=\frac{1{\cdot}51}{4{\cdot}541}$	$=0{\cdot}3325=$	8·31	7·5
4 double cells,	$\frac{4-2{\cdot}49}{\frac{4}{2}+0{\cdot}541}=\frac{1{\cdot}51}{2{\cdot}541}$	$=0{\cdot}5942=$	14·85	13·7
4 treble cells,	$\frac{4-2{\cdot}49}{\frac{4}{3}+0{\cdot}541}=\frac{1{\cdot}51}{1{\cdot}871}$	$=0{\cdot}8071=$	20·17	21
4 quadruple cells,	$\frac{4-2{\cdot}49}{\frac{4}{4}+0{\cdot}541}=\frac{1{\cdot}51}{1{\cdot}541}$	$=0{\cdot}9799=$	24·5	25·5
4 quintuple cells,	$\frac{4-2{\cdot}49}{\frac{4}{5}+0{\cdot}541}=\frac{1{\cdot}51}{1{\cdot}341}$	$=1{\cdot}126=$	28·15	30
5 single cells,	$\frac{5-2{\cdot}49}{5+0{\cdot}541}=\frac{2{\cdot}51}{5{\cdot}541}$	$=0{\cdot}453=$	11·33	11·25
5 double cells,	$\frac{5-2{\cdot}49}{\frac{5}{2}+0{\cdot}541}=\frac{2{\cdot}51}{3{\cdot}041}$	$=0{\cdot}8254=$	20·63	20·5
5 treble cells,	$\frac{5-2{\cdot}49}{\frac{5}{3}+0{\cdot}541}=\frac{2{\cdot}51}{2{\cdot}208}$	$=1{\cdot}137=$	28·42	28·7
5 quadruple cells,	$\frac{5-2{\cdot}49}{\frac{5}{4}+0{\cdot}541}=\frac{2{\cdot}57}{1{\cdot}791}$	$=1{\cdot}401=$	35·04	35·2
10 single cells,	$\frac{10-2{\cdot}49}{10+0{\cdot}541}=\frac{7{\cdot}51}{10{\cdot}541}$	$=0{\cdot}7124=$	17·81	15·7
10 double cells,	$\frac{10-2{\cdot}49}{\frac{10}{2}+0{\cdot}541}=\frac{7{\cdot}51}{5{\cdot}541}$	$=1{\cdot}355=$	33·88	33·7
15 single cells,	$\frac{15-2{\cdot}49}{15+0{\cdot}541}=\frac{12{\cdot}51}{15{\cdot}541}$	$=0{\cdot}8117=$	20·29	18·7
20 single cells,	$\frac{20-2{\cdot}49}{20+0{\cdot}541}=\frac{17{\cdot}51}{20{\cdot}541}$	$=0{\cdot}8524=$	21·31	22.

The agreement of the calculated and experimental results under such complicated circumstances, as shown in the last two columns of the preceding Table, must, I think, be deemed very satisfactory; and it is worthy of remark, that the result just named, of the independent experiment with the single cell, 25 cubic inches, is almost identical with that deduced from the experimental determination of five cells; taking 11·25 cubic inches to represent accurately the fraction 0·453: and indeed agree very

closely with the calculated results of the above Table, whatever combination be taken as the foundation of the calculation.

In the experiments already alluded to, which I performed in conjunction with Professor WHEATSTONE, the cells of the battery used were of the same character as the last, but with an efficient length of 20 inches, or 3·33 times greater. The duration of each experiment was in this case one minute.

Upon making the calculations for these, E being = 1, R = 1, e was found = 2·85, by comparing the results of five single with those of ten double cells; and r (by a mean of seven experiments) = 1·757. Hence we find,

		Calculation. Cubic inches.	Experiment. Cubic inches.
5 single cells,	$\frac{5-2\cdot85}{5+1\cdot757}=\frac{2\cdot13}{6\cdot757}=0\cdot3182$	= 7·31	6
5 double cells,	$\frac{5-2\cdot85}{\frac{5}{2}+1\cdot757}=\frac{2\cdot13}{4\cdot257}=0\cdot505$	= 11·59	11
5 treble cells,	$\frac{5-2\cdot85}{\frac{5}{3}+1\cdot757}=\frac{2\cdot13}{3\cdot423}=0\cdot6281$	= 14·4	14
5 quadruple cells,	$\frac{5-2\cdot85}{\frac{5}{4}+1\cdot757}=\frac{2\cdot13}{3\cdot007}=0\cdot715$	= 16·44	15·66
10 single cells,	$\frac{10-2\cdot85}{10+1\cdot757}=\frac{7\cdot13}{11\cdot757}=0\cdot6081$	= 13·98	12·25
10 double cells,	$\frac{10-2\cdot85}{\frac{10}{2}+1\cdot757}=\frac{7\cdot13}{6\cdot757}=1\cdot058$	= 24·33	20
20 single cells,	$\frac{20-2\cdot85}{20+1\cdot757}=\frac{17\cdot13}{21\cdot757}=0\cdot7882$	= 18·55	17·25.

These results again exhibit a general accordance with the calculation, but by no means so close as the preceding. I was therefore induced to repeat the experiments with great care. The following Table shows the results, which it will be seen closely correspond with those deduced by the formula.

By a mean of fourteen experiments r was again determined to be in this battery 1·725 R.

Taking, as before, E = 1, R = 1, and e = 2·49, we obtain from

		Calculation. Cubic inches.	Experiment. Cubic inches.
5 single cells,	$\frac{5-2\cdot49}{5+1\cdot725}=\frac{2\cdot51}{6\cdot725}=0\cdot3732$	= 8·58	8·875
5 double cells,	$\frac{5-2\cdot49}{\frac{5}{2}+1\cdot725}=\frac{2\cdot51}{4\cdot225}=0\cdot5941$	= 13·66	13·5

		Calculation. Cubic inches.	Experiment. Cubic inches.
5 treble cells,	$\frac{5-2{\cdot}49}{\frac{5}{3}+1{\cdot}725}=\frac{2{\cdot}51}{3{\cdot}391}=0{\cdot}738$	$=16{\cdot}97$	17·0
5 quadruple cells,	$\frac{5-2{\cdot}49}{\frac{5}{4}+1{\cdot}725}=\frac{2{\cdot}51}{2{\cdot}975}=0{\cdot}8437$	$=19{\cdot}4$	20·0
10 single cells,	$\frac{10-2{\cdot}49}{10+1{\cdot}725}=\frac{7{\cdot}51}{11{\cdot}725}=0{\cdot}6408$	$=14{\cdot}73$	15·25
10 double cells,	$\frac{10-2{\cdot}49}{\frac{10}{2}+1{\cdot}725}=\frac{7{\cdot}51}{6{\cdot}725}=1{\cdot}116$	$=25{\cdot}68$	25·5
20 single cells,	$\frac{20-2{\cdot}49}{20+1{\cdot}725}=\frac{17{\cdot}51}{21{\cdot}725}=0{\cdot}8062$	$=18{\cdot}54$	18·00.

The maximum work of a single circuit of this battery was found to be 9·95 grs. of zinc per minute, which is equivalent to twenty-three cubic inches of the mixed gases. A similar agreement of this independent result which has been taken as the unit in the preceding table $\left(\text{for } \frac{E}{R}=1\right)$ with those which would be afforded by any combination of cells taken as the foundation of the calculation may be also observed, as in the case of the table deduced from experiments with the smaller battery.

When a number of cells of different power are included in the same circuit, the expression becomes

$$\frac{n\,E+n'\,E'-e}{(n+n')\,R+r}=A,$$

supposing that R remains the same as in the regular circuit, and E' represents the electromotive force of the new element, and n' the number of the new elements included.

It will further, on a little consideration, be obvious why a half-zinc rod may be substituted for a whole one in a series, without any perceptible diminution of the effect, as I found upon a former occasion*. The effect of diminishing the length of the rod is principally to increase the distances between the metals, as the dimensions of the mean section of the electrolyte will scarcely be altered, owing to the comparatively small surface of the generating metal, even when entire. The general formula will then become

$$\frac{n\,E-e}{n'\,R+n''\,R'+r}=A,$$

when n' represents the number of ordinary zinc rods, n'' the number of shortened ones, and R' the increased resistance offered by each of the latter.

The mean distance between the metals will, perhaps, be increased one-third by

* Philosophical Transactions, 1836, p. 127.

halving the length of the zinc; and the resistance R presented by that cell, varying directly as the distance, will be $1\frac{1}{3}$ instead of one.

The formula, therefore, for 20 small cells with 19 zinc rods of the ordinary size, and 1 short one, becomes

$$\frac{20 - 2{\cdot}49}{19 + 1{\cdot}33 + 0{\cdot}541} = \frac{17{\cdot}51}{20{\cdot}871} = 20{\cdot}97 \text{ cubic inches}$$

instead of

$$\frac{20 - 2{\cdot}49}{20 + 0{\cdot}541} = \frac{17{\cdot}51}{20{\cdot}541} = 21{\cdot}31 \text{ cubic inches,}$$

when the zincs are all of the full length.

Thus with a small series of five cells with entire rods

$$\frac{5 - 2{\cdot}49}{5 + 0{\cdot}541} = \frac{2{\cdot}51}{5{\cdot}541} = 11{\cdot}33 \text{ cubic inches;}$$

with four entire rods and one half rod,

$$\frac{5 - 2{\cdot}49}{4 + 1{\cdot}33 + 0{\cdot}541} = \frac{2{\cdot}51}{5{\cdot}871} = 10{\cdot}69 \text{ cubic inches;}$$

the differences not being appreciable in the usual mode of measurement.

In an arrangement containing one or more reversed cells, the formula becomes

$$\frac{(n - n')\,\mathrm{E} - e}{(n + n')\,\mathrm{R} + r} = \mathrm{A},$$

where n' represents the number of reversed cells.

My fifth letter contains the results of experiments with the battery under such circumstances. Upon comparing these results with those of the formula just given, the discrepancies were found to be constant and considerable; such however as might be accounted for by supposing that each reversed cell introduced, in addition to the reversed current, an extra resistance. Upon searching for this resistance it was proved to exist, and its cause manifested by the following experiments.

Ten small cells, charged in the usual manner, were arranged in series, including a voltameter, and an additional cell with a similar charge; substituting a copper rod in the interior for one of zinc.

In four minutes seven cubic inches of gas were collected in the voltameter; the action then suddenly declined in intensity, and in the next four minutes only $3\frac{1}{2}$ cubic inches of gas were given off. Upon examining the copper rod it was found coated with a film of oxide: this was wiped off, and a bright metallic surface was again exposed, and on once more connecting the battery, seven cubic inches of gas were given off, as before, in four minutes. The quantity again declined. This was several times repeated, and always with the same general results. It is hence evident, that when copper is made the zincode in the series, a layer of oxide is deposited upon it, which is not immediately dissolved by the acid, and offers a resistance which will vary according to its thickness; and this again will much depend upon the size of the surface.

This is, moreover, not the only point for consideration; for it is probable that the hydrogen accumulated upon the zinc of the reversed cells would exalt its electromotive force, so that $-$ E would be somewhat increased; and upon making the calculation upon these amended data the formula becomes

$$\frac{n\mathrm{E} - n'\mathrm{E}' - e}{(n + n')\mathrm{R} + r + n'r'} = \mathrm{A}, \text{ or } \frac{n\mathrm{E} - n'\mathrm{E}' - e}{n\mathrm{R} + n'\mathrm{R}' + r},$$

taking in the first formula r' to represent the additional resistance introduced by each reversed cell, and in the second R$'$ as the total resistance in each reversed cell, and E$'$ the increased electromotive force in each of the same reversed cells.

In the following calculation $\mathrm{E} = 1$, $\mathrm{R} = 1$, $e = 2{\cdot}85$, $r = 1{\cdot}725$, $\mathrm{E}' = 1{\cdot}1$, $r' = 0{\cdot}5$.

It is assumed that r' is a constant quantity, which may be pretty accurately true when the copper surface is so large in relation to the zinc as in the present case.

			Calculation. Cubic inches.	Experiment. Cubic inches.
20 direct,	$\frac{20 - 2{\cdot}85}{20 + 1{\cdot}725}$	$= \frac{17{\cdot}05}{21{\cdot}725}$	$= 18{\cdot}18$	17·5
1 reversed,	$\frac{19 - 2{\cdot}85 - 1{\cdot}1}{20 + 1{\cdot}725 + 0{\cdot}5}$	$= \frac{15{\cdot}05}{22{\cdot}225}$	$= 15{\cdot}57$	15·5
2 reversed,	$\frac{18 - 2{\cdot}85 - 2{\cdot}2}{20 + 1{\cdot}725 + 1{\cdot}0}$	$= \frac{12{\cdot}95}{22{\cdot}275}$	$= 13{\cdot}1$	12·75
3 reversed,	$\frac{17 - 2{\cdot}85 - 3{\cdot}3}{20 + 1{\cdot}725 + 1{\cdot}5}$	$= \frac{10{\cdot}85}{23{\cdot}225}$	$= 10{\cdot}74$	10·5
4 reversed,	$\frac{16 - 2{\cdot}85 - 4{\cdot}4}{20 + 1{\cdot}725 + 2{\cdot}0}$	$= \frac{8{\cdot}75}{23{\cdot}275}$	$= 8{\cdot}48$	8·5
5 reversed,	$\frac{15 - 2{\cdot}85 - 5{\cdot}5}{20 + 1{\cdot}725 + 2{\cdot}5}$	$= \frac{6{\cdot}65}{24{\cdot}225}$	$= 6{\cdot}31$	5·5
6 reversed,	$\frac{14 - 2{\cdot}85 - 6{\cdot}6}{20 + 1{\cdot}725 + 3{\cdot}0}$	$= \frac{4{\cdot}55}{24{\cdot}725}$	$= 4{\cdot}23$	3·5
7 reversed,	$\frac{13 - 2{\cdot}85 - 7{\cdot}7}{20 + 1{\cdot}725 + 3{\cdot}5}$	$= \frac{2{\cdot}45}{25{\cdot}225}$	$= 2{\cdot}23$	1·625
8 reversed,	$\frac{12 - 2{\cdot}85 - 8{\cdot}8}{20 + 1{\cdot}725 + 4{\cdot}0}$	$= \frac{0{\cdot}35}{25{\cdot}725}$	$= 0{\cdot}31$	1·16

The agreement of the experiments with the calculations is not as close as before, especially in the lower part of the table, but may I think be deemed satisfactory, as a first approximation to the solution of a problem of a most complicated nature.

The influence of the dimensions of the plates of a voltameter upon the amount of decomposition may also be submitted to calculation in the same way. This influence will, of course, be most perceptible when a small number of elements presenting a large surface is employed; whereas, when a numerous series is made use of, the dimensions of the electrodes are of little consequence. Some experiments which I have made with a large voltameter, kindly lent to me for the purpose by Mr. Gassiot,

will place this in a striking point of view. The voltameter consisted of five pairs of platinum plates, each four inches by $3\frac{3}{4}$ inches, at an average distance of half an inch apart. These were so arranged that any number of them might at pleasure be connected with a battery.

20 cells of the small battery were so arranged as to form a series of 5 quadruple cells, and then connected with one pair of plates of the voltameter. By a mean of two experiments they gave 26·2 cubic inches of gases for five minutes.

When all the plates of the voltameter were connected with the battery, the product of gases for five minutes was 32 cubic inches.

The same battery arranged to form a series of 20 single cells, furnished with one pair of plates 16 cubic inches, and with all the plates the result was the same.

Now by experiment, if $E = 1$, $e = 2{\cdot}49$, $R = 1$, $r =$ resistance with one pair.

$$\left.\begin{array}{ll}(1.) & 20 \text{ with one pair} = \dfrac{20 - 2{\cdot}49}{20 + r} = \dfrac{17{\cdot}51}{20 + r} = 16 \text{ cubic inches.} \\[2ex] (2.) & 20 \text{ with five pairs} = \dfrac{20 - 2{\cdot}49}{20 + \frac{r}{5}} = \dfrac{17{\cdot}51}{20 + \frac{r}{5}} = 16 \text{ cubic inches.}\end{array}\right\}$$

$$\left.\begin{array}{ll}(3.) & 5 \text{ quadruple with one pair} = \dfrac{5 - 2{\cdot}49}{\frac{5}{4} + r} = \dfrac{2{\cdot}51}{1{\cdot}25 + r} = 26{\cdot}2 \text{ cubic inches.} \\[2ex] (4.) & 5 \text{ quadruple with five pairs} = \dfrac{5 - 2{\cdot}49}{\frac{5}{4} + \frac{r}{5}} = \dfrac{2{\cdot}51}{1{\cdot}25 + \frac{r}{5}} = 32 \text{ cubic inches.}\end{array}\right\}$$

Since the electromotive forces in the two last expressions are the same, we can, by comparing them, ascertain the value of r. Thus

$$1{\cdot}25 + r : 1{\cdot}25 + \frac{r}{5} : : 32 : 26{\cdot}2$$

$$r = \frac{18{\cdot}125}{52{\cdot}4} = \frac{1}{3} \text{ nearly.}$$

Now substituting this value of r in the expressions (1.) and (2.), and adopting the experimental result of 16 cubic inches, we obtain for

Calculation.

$$(1.) \text{ the fraction } \frac{17{\cdot}51}{20{\cdot}33} = 16{\cdot}2 \text{ cubic inches.}$$

$$(2.) \text{ the fraction } \frac{17{\cdot}51}{20{\cdot}06} = 16{\cdot}0 \text{ cubic inches.}$$

The calculated results it will be seen almost coincide with each other, as do the experiments.

By the substitution of different values for R and r in the formula, it will be found that every different arrangement must have a distinct number in series, which it will be most advantageous to work with, and this number will vary in the same arrangement, with the nature of the electrolyte, and also with the size of the battery plates. It will appear from calculation, that the most advantageous combination is that in

which the value of A $\left(\text{in the formula } \frac{n\text{E} - e}{n\text{R} + r} = \text{A}\right)$ most nearly approaches to 0·5. It will therefore vary even in batteries of the same chemical construction; increasing as R diminishes in proportion to r: or in other words, when the plates are large, a more numerous series is required, than when small, to produce the most advantageous results. This is likewise the case when the exterior resistance is increased: in both cases R is virtually diminished in respect to r.

It is evident from the preceding observations, that all the comparisons hitherto made by different experimenters between the general relative powers of different batteries are faulty, inasmuch as they only hold good in the particular cases to which the experiments are limited; and one battery of a certain size may be preferable for one kind of decomposition, and yet may allow of considerable useless expenditure of power when a different electrolyte is subjected to its action. As, however, great stress has, by some, been laid on comparisons of this kind, it may not be amiss to give a few experimental results.

In the following arrangements the cylindrical form was employed. In each case the platinum cylinders were 4 inches high, and $1\frac{3}{4}$ inch in diameter. The zinc rods were half an inch thick, the exciting fluid was placed in a porous earthenware tube 1 inch in diameter. Three cells was the number employed in each experiment. The measures employed was the quantity of mixed gas produced from the voltameter during 5 minutes.

Exterior liquids.	Exciting liquids.	Gas in five minutes.
		cubic inches.
Acid sulphate of copper..................	Dilute sulphuric acid, specific gravity 1·126	3·0
Nitric acid, specific gravity 1·40	Dilute sulphuric acid, specific gravity 1·126	14·0
Bichromate of potash, specific gravity 1·050..	Dilute sulphuric acid, specific gravity 1·126	3·1
Bichromate of potash, $\frac{1}{8}$ sulphuric acid......	Dilute sulphuric acid, specific gravity 1·126	5·5
Nitrate of copper, neutral saturated solution	Dilute sulphuric acid, specific gravity 1·126	3·5
Nitric acid, specific gravity 1·40	Dilute nitric acid, specific gravity .. 1·056	8·5

The eligibility of a liquid in the construction of a battery will, of course, be much influenced by its conducting power: and it would at first sight appear that this might be easily determined by placing the different liquids, in succession, in the same voltameter, or experimental cell, and transmitting through them a constant current of known power; measuring the retarding influence of each by another voltameter charged in the usual way with dilute sulphuric acid, and included in the same circuit. The following are the results of some experiments so performed. The current from ten cells of the small constant battery was employed:—

Liquid tested.	Gas from voltameter in five minutes. Cubic inches.
Nitric acid, specific gravity 1·4	11
Nitric acid + $\frac{1}{8}$ sulphuric acid	11
Dilute sulphuric acid (standard)	9·2
Dilute sulphuric acid saturated with sulphate of copper . .	9·2
Saturated solution of sulphate of copper	7·9
Bichromate of potassa, specific gravity 1·050	5·6

Let us however consider these results with reference to the formula. The expression for the arrangement used becomes

$$\frac{n\,\mathrm{E} - e - e'}{n\,\mathrm{R} + r + r'},$$

in which e' signifies the contrary electromotive force, introduced by the accumulation of the ions on the plates of the voltameter containing the liquid tested, and r' the resistance offered by the same. It is clear that we cannot estimate r', which we are attempting, unless e' is known or remains constant: now e' is not constant, since with nitric acid it vanishes probably altogether, and varies with each of the other substances employed.

If chloride of platinum were not too expensive to allow of its being employed as the exterior part of the electrolyte in contact with a platinum, conducting plate, e', or the contrary electromotive force would be wholly annihilated, as nothing but platinum would be thrown down upon the platinum, and it would constitute the most perfect possible arrangement, but would not much, if anything, exceed the efficiency of nitric acid.

In the nitric acid battery the electromotive force is nearly double that of the sulphate of copper arrangement, and consequently one cell of that construction is capable of effecting the decomposition of dilute sulphuric acid. It is evident that a similar series of calculations might be made for this battery and others in which different electrolytes are employed; R varying as before with the size and distance of the plates.

I have, however, done enough for the accomplishment of my present purpose; but must not conclude without expressing my obligations to my friend Dr. Miller for his able assistance, both in the performance of the experiments and the calculations of the results which I have now the pleasure of communicating to you.

I remain, my dear Faraday,

Very faithfully yours,

J. F. Daniell.

King's College,
12*th April,* 1842.

IX. *On the ultimate distribution of the Air-passages, and the formation of the Air-cells of the Lungs.* By William Addison, *Esq., F.L.S., Member of the Royal College of Surgeons, and of the Council of the Worcestershire Natural History Society.* *Communicated by* Robert B. Todd, *M.D., F.R.S.*

Received March 3,—Read April 7, 1842.

THE opinions of anatomists have been much divided as to the manner in which the bronchial tubes terminate; whether the cells composing a lobule of the lungs have free communication with each other, or whether each cell, without any such communication, receives the inspired air by a single bronchial ramification only.

The latter opinion, derived from the results of Reisseissen's investigations, prevails.

Malpighi was the first to describe the *air-vesicles* of the lungs, and the *air-tubes* ending in them*.

Helvetius attempted to prove that these *Malpighian vesicles* were nothing more than common cellular tissue, diffused without order through the lungs, and that the air proceeding thither through the minute air-tubes, not only passes easily from cell to cell, but likewise from the lobules into their interstices, and finally diffuses itself through the whole lung.

Haller adopted the opinions of Helvetius. "The vesicles of the lungs," he says, "do not receive the air by a single orifice from the windpipe as into an oval grape or phial, but the air exhaling from the least branches freely spreads from any one part of the lungs into all the rest, and returns again in like manner; neither is the cellular fabric of the intervals between the lobules shut up from the vesicles of the lungs, nor are the lesser lobes surrounded by any peculiar membrane†."

Reisseissen, in his work *De Fabrica Pulmonum,* discourses of the labours of his predecessors, and refers particularly to the opinions entertained by Helvetius and Haller; and then, aided in his researches by a microscope, and by various methods of inflation and injection, he attempts to controvert them, and to prove that the cells in each lobular subdivision have no communication with those of the adjoining ones, in the manner of cellular tissue. "The air-cells," he says, "are the *culs de sac* terminations of the air-tubes, and are perfectly independent of one another‡."

* M. Malpighi de Pulm. Epistol. 1 and 2, ad A. Borellum, 1661. Epistola 1. de Pulm. Published at the end of the Exercit. de Visc. Struct. p. 220, &c.

† Haller (Von Albert), Elementa Physiologiæ: Cap. De Respiratione.

‡ "Inde jam facile colligitur, singulas per pulmonum faciem vesiculas, cellulasve aëriferas, cæcos esse extremorum canaliculorum fines, easque ingenti numero distributas, massam illam conficere quæ spumosa ut est plurimis contextus cellulosus videbatur."—*Op. citat.*, p. 56.

Cruveilhier and Majendie, however, describe the air-cells as freely communicating with each other, in the interior of each lobule; but I am not aware that either of these authors has given any detailed or minute description of the aëriferous structure of the lung*.

Having been engaged in investigating by the microscope the seat and nature of tubercles in the lungs, and having examined the structure, recent and dry, in every possible way I could devise, I nevertheless always failed to discover any *tubes* ending in *culs de sac*; on the contrary, I always saw air-cells communicating with each other in every section I made.

I therefore repeated several of Reisseissen's experiments, and instituted others, from which I derived ample evidence that *the bronchial tubes*, after dividing into a multitude of minute branches which take their course in the cellular interstices of the lobules, *terminate* in their interior *in branched air-passages, and* freely *communicating air-cells*.

In a fœtal lung the bronchial ramifications in the interior of a lobule, or the *intralobular ramifications*†, have a regular branched arrangement, subdividing in all directions, somewhat dichotomously, and terminating at the boundary of the lobule in closed extremities. It is not, however, at the boundary of the lobule only that these closed extremities or *culs de sac* terminations of the intralobular bronchial ramifications are placed, many of them may be seen in the interior of a lobule, lying against and pressing upon the sides of the adjoining branches (*a*), Plate XII. fig. 8.

It is important to remark, that there are *no anastomoses* to be seen between the intralobular bronchial branches; each branch pursues its own independent course, until it terminates in a closed extremity.

Anatomical writers generally use the terms *air-vesicles* and *air-cells* synonymously, so that they are convertible terms; but strictly speaking, an air-vesicle is an air-bubble, and may exist either in or out of a pulmonary air-cell. It is not necessary to the existence of an air-bubble, that it should be contained in a membranous envelope; hundreds of them may not only exist, but in any slightly viscous liquid may even press against each other, without losing their figure or globular isolation.

In a fœtal lung neither air-bubbles nor air-cells exist; but when an animal respires, the entrance of the air into the lungs inflates all the lobules to twice or three times their fœtal dimensions, and the *intralobular bronchial ramifications* experience a great and important change both in figure and character. The delicate membrane composing them opposes an unequal degree of resistance to the pressure of the air, which is very considerable, and it is consequently distended into little globular inflations, forming a series of communicating cells, which are immediately and perma-

* Cruveilhier's Anatomy, by A. Tweedie, M.D., F.R.S., p. 552. Majendie's Lectures.

† I have adopted the appropriate and now universally received terms of Mr. Kiernan, which exactly express a very necessary distinction between the bronchial ramifications in the cellular interstices of the lobules, which are always tubes, and those in the interior of the lobules, which are tubular only in the fœtus.

nently occupied by air-bubbles, in the mass of which all trace of the symmetry of their branched arrangement is entirely lost or obscured. The rounded inflations of one branch meeting on all sides those of the adjoining branches, are moulded by pressure into pentagonal or hexagonal forms, which are the figures of the air-cells, fig. 9.

Branched passages, however, still exist, and form a communication between the cells; but these passages are now neither tubular nor cylindrical. It is therefore necessary to distinguish them, and I have called them Lobular Passages, an appropriate term suggested to me by Dr. R. B. Todd.

The air-cells have not an indiscriminate and general intercommunication throughout the interior of a lobule. I have before observed that there are no anastomoses between the intralobular bronchial ramifications; hence the air-cells formed along the branch (*b*), fig. 8, do not communicate with those in the branch (*c*), except by means of their common opening into a larger branch at (*d*), and so on for each branch respectively.

Experiment 1.—Take a very thin section of inflated and dried lung, and submit it to an examination by the microscope. A great number of large and well-defined Oval Foramina, (*a*, *a*) fig. 1, with a sharp and delicate edge, will be seen thickly distributed among the cells. Frequently three, four, or five of them (*b*, *b*) may be seen close together, and whichever way the section be made, they are equally numerous and conspicuous. These foramina are evidently not portions of bronchial tubes, for they have no uniform cylindrical wall, which is necessary to constitute a tube. By gently altering the focus of the microscope you may look down through the uppermost foramina into the interior of air-cells situated laterally below them, and several foramina and cells may thus be brought successively into view (*c*, *c*).

These foramina are portions of the *lobular passages*, and if the section be taken from the surface of the lung, including the pleura, they are smaller, and placed at more equal distances from each other, than when made from the interior of the organ, fig. 2; which is exactly the result that would accrue from a division of branched passages, in the former case (fig. 2.) approaching their terminations, and in the latter (fig. 1.) nearer the point whence the branches emanate.

Experiment 2.—I injected with mercury a small bronchial tube in the lung of an Ox; leading towards the thin margin of the organ; the metal appeared at the surface, forming a mass of minute globules. Having made an incision in the interval between two lobules and inflated the cellular tissue, I was enabled carefully to dissect away the pleura, and I then observed through a lens that the globules were contained in delicate membranous sacs, forming rounded eminences projecting from the tissue. I then separated several lobules from each other, and saw the mercury at the surface of every lobule, presenting rounded eminences similar to those observed at the surface of the lung. On examining these rounded eminences or globules in the microscope, I perceived that the mercury was not inclosed in a simple sac or cell, but in a divided

or multilocular cavity. Nor is it difficult to comprehend the character of these multilocular cells at the surface, when we conceive the nature of the structure of a lobule, consisting of numberless small branches of a ramified tube, which the atmosphere at birth distends into cells. The extremities of these branches, evolving or shooting forth under the pressure of the air, meet with resistance and support from the adjoining lobules, and being as it were thrown back upon themselves, form the multilocular cavities or cells I have described (*b, c'*) fig. 8. WAGNER's figure represents these terminal cells only*.

Experiment 3.—Having inflated a recent lung, I cut off a small portion, and examined it as an *opake object* by the microscope; I found all the oval foramina occupied by large air-bubbles, other bubbles of various sizes occupying the surrounding cells. I then placed *a very small* piece between two slips of glass, which were so arranged under the microscope that I could gently and gradually press them together, still keeping the object (*now viewed transparent*) in focus. I then observed the air-bubbles changing their situation, not by moving equably through any tube or cylindrical passage, but by sudden starts from cell to cell. I frequently saw a large bubble of air become compressed for a moment in passing from one cell to another, and sometimes divide into two smaller bubbles, one of which passed on to another cell, the other retiring to the spot from which a momentary pressure had removed it. I have frequently watched a bubble of air pass through three or four cells in succession, the communication between them not being through a tubular passage, but by limited openings (oval foramina) leading from cell to cell.

It does occasionally happen that a small portion of bronchial tube may be included in the object thus submitted to examination, and if so, when the glasses are pressed together, the air-bubbles glide easily and readily through it. The bubbles of air formed in the lungs are of all dimensions, some large, some small, and others so minute as not to measure more than $\frac{1}{1000}$th or $\frac{1}{800}$th of an inch in diameter; hence three, four or more may occupy a single cell, and the heterogeneous adhesion between them and the tissue is so strong, that it is impossible to expel all of them by pressure. They may, however, be removed from very thin sections of recent lung by two or three days' maceration in water, and the pulmonary network is by this means rendered very distinct; and if such sections be carefully examined by a lens, *lobular passages may be seen partially laid open, disclosing a series of communicating cells* (*a, a, b*, fig. 3.).

Experiment 4.—If the lungs of a Rabbit be allowed to macerate for two or three days, all the air-bubbles at the thin edge of the organ will be removed, and this portion assimilated to a fœtal state. Having prepared a lung in this way, I poured mercury into the trachea, and allowed the metal by its own weight to traverse the air-tubes and passages; it appeared at the surface of some of the lobules in the form of little globules (*a*, fig. 4.), in others *as beaded* or *nodulated branches* (*b.*). By press-

* Icones Physiologicæ, tab. xv. fig. 8, 1839.

ing the mercury onward, these beaded branches became more and more numerous, smaller ones proceeding not only from the extremities of those first seen, but shooting out from them laterally in all directions; by continuing a little gentle pressure, all symmetrical arrangement was lost in a mass of minute globules (*c*). These beaded branches evidently combine the character both of cells and passages; each bead or globular inflation is an air-cell, communicating with others on either side in such manner as to form branched passages*.

If the pleura be stripped off from the lung of a fœtal Calf, the lobules may be readily separated from each other, and their subdivisions are carried to a great extent. I have measured several from $\frac{1}{20}$ to $\frac{1}{30}$th of an inch only. The smallness of the ultimate lobular subdivisions may also be seen by removing a small strip from the thin margin of a lung, and slightly compressing it between two slips of glass, figs. 5 and 6.

The lobules have an irregular polygonal figure of from four to six sides: after respiration the sides are flatter, and the angles sharpened by the pressure of the adjoining lobules.

Experiment 5.—I poured mercury into the lungs of a fœtal Calf by the trachea,

* Reisseissen was the first who noticed the globular distentions or nodules formed on the extreme bronchial branches when a lung is injected with mercury; but he appears to have looked upon them as unnatural or abnormal, produced by the weight of the metal, not considering that the weight or pressure of the air rushing into a fœtal lung is much greater than the weight of any column of mercury that would usually be employed to inject a lung. Speaking of a lobule injected with mercury, he observes, "Hæc fabrica clarius etiamnum perspicietur, lobulo ejusmodi intra duas laminas vitreas comprehenso, ac microscopio subjecto. Laminæ autem quadamtenus sunt comprimendæ ut hydrargyrum, ab aëre intus residuo usque repulsum extremos in fines impellatur. Sic apparebit, canaliculos ad extremum usque marginem certo quodam ordine, eoque constantissime servato in ramulos excurrere, horumque diametros ad rationem procedentis ramificationis decrescere, ipsam vero in ramulos divisionem ad finem adeo increbrescere, ut ex singulis cujusque ramuli locis novi circumquaque proveniant, qui, hydrargyro impleti, quasi nodulos referunt; denique extremos illorum fines tam breves evadere, ut speciem tantum globulorum dimidiatorum exhibeant instar brassicæ botrytidos stipatorum.

"Ne quis autem objicere posset, partes per se tenerrimas hydrargyri pondere extendi, idque ipsum, in globulos discedere valde pronum, illusionibus opticis occasionem dare, aliud institui experimentum, quod, quum tales præcidat dubitationes, viarum spiritalium fines clarius etiam armato oculo repræsentat. Statui itaque illas spiritu tantum impletas, nec ulla adhibita vi novo examini submittere. Pulmonem vero quam recentissimum, eumque teneriori ex animali exemptum (vitulinus opinor optimus est) aquæ submergi deindeque seponi jussi. Tum, sublatum post aliquot dies, quum demisso spiritu maxima quidem ex parte collapsus est, nonnulli tamen lobuli aërem inclusum etiamnum retinerent, calida curavi perfundendum, sic ut rarefacto per calorem spiritu, distenti ramuli in subjecta rubicunda bullarum collapsarum massa facile adspectui se præberent. Deinde, aëris columella scalpelli ope extremos ad fines promota, eandem vidi, ut antea distributionem, præterquam quod canaliculi minus intenti cylindros exactiores referebant. Evidentissime autem cognosci potest, canaliculos ad extremum productos cæcos in fines, sive vesiculas pulmonales abire, lobulo tali intra lamellas vitreas microscopio ita subjecto, ut a spectro reflexorio pelluceat, et illis subinde leviter agitatis, aër modo antrorsum, modo laterales in ramos impellatur. Neque tandem vesicularum forma fallere quenquam potest, pro distentis sacculis illas habentem, vel bullulis globosis, quæ extremis canalibus sint adnexæ, quum ambitum ipsarum ad ramulos, unde prodeunt relatum, perinde se habere, atque ramos ad truncum clarissime perspiciat.

"*Hæc experimenta abunde, ut videtur, ostendunt, vias pulmonum spiritales canales teretes esse ad finem cæcos, membranaceos, ex tunica videlicet tracheæ mucosa conformatos, aëri, ut supra commemoratum est, plane impermeabiles.*"

and allowed it by its own weight to trickle down the bronchial tubes which were filled with the metal, and were very conspicuous at the thin margin of the organ. I placed a portion of the injected thin margin of the lung between two plates of glass, and on using slight pressure, the mercury at the extremities of the injected branches was forced into still smaller nodulated branches, which divided and subdivided in an unvaried branched order, (*a*) figs. 5 and 6; by using a little more pressure their numbers increased, the symmetry of the branches being readily detected by the microscope; but ultimately, by continuing the pressure, all symmetry was lost in a mass of minute globules (*a*). The same effects were produced by pressing the mercury in the bronchial tubes onward between the finger and thumb without using the plates of glass.

With a good light and a power magnifying 120 times linear, the globules of mercury are seen to be inclosed in cellular cavities formed laterally on branched passages. In the small branches the metal appears in round globules; it is less globular in the larger branches, and a disposition to the formation of cells may be detected by the depressed lines seen on the column of mercury in branches of still greater magnitude.

I have in my possession a preparation containing lobules from the thin margin of a fœtal lung which were partially distended by air, sufficient to show the regular branched symmetry of the air-tubes to their ultimate terminations; establishing a perfect analogy between them and the secreting tubes of glandular organs. The air with which the tubes were partially distended has been absorbed by the fluid in which the preparation is preserved, and membranous septa are everywhere visible in their interior. The pulmonary cells are evidently formed by the pressure of the air against the sides of the tubes in the intervals between these folds (fig. 8.). A careful examination of the membranes of the air-cells by the microscope in a thin section of dried inflated lung will be sufficient to convince any one that they do not form round nor even rounded cells, but that they are perfectly flat membranous plates, circumscribing polyhedric spaces. When healthy and recent they are exceedingly tough and elastic. I have often found that the tissue of the lungs may be stretched to twice its dimensions without rupturing them. They will bear the scrutiny of the highest powers of the microscope, and are characterized by several peculiar ovate bodies which form a part of their structure. They are also marked by numerous delicate lines, which are, no doubt, uninjected vessels of the capillary network. They possess an epithelium in the form of large round nucleated scales, and from one to fifteen or more nuclei may be counted in a single scale. A great many nuclei without any epithelium envelope may be seen upon them, but I have never satisfied myself that they possess the ciliated cylinder epithelium so abundant in the trachea and the bronchi.

The dimensions of the air-cells, as might be expected from the preceding details of their structure and formation, gradually increase with age, but in healthy women they are always smaller than in healthy men at the same period of life. Taking the recent lung of a healthy man, aged forty-five, as the mean between the small cells of

Fig. 1.

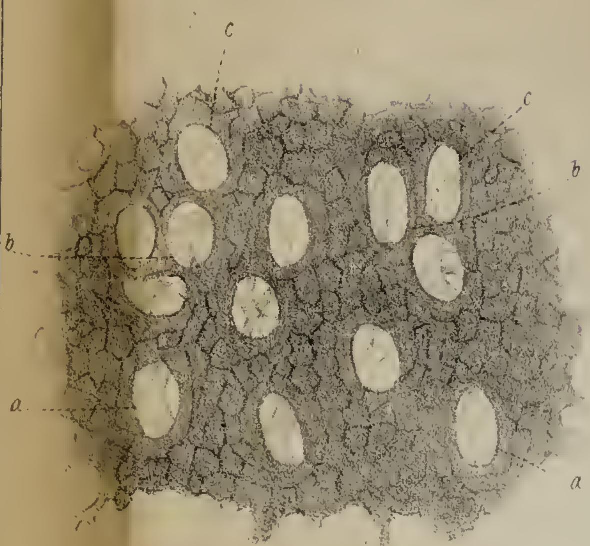


Fig. 2.

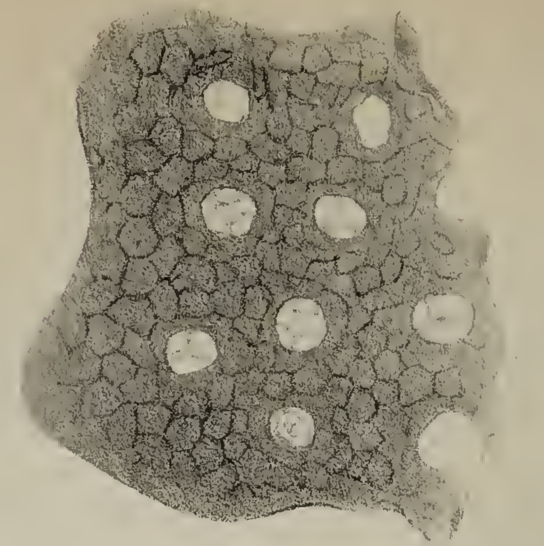


Fig. 3.

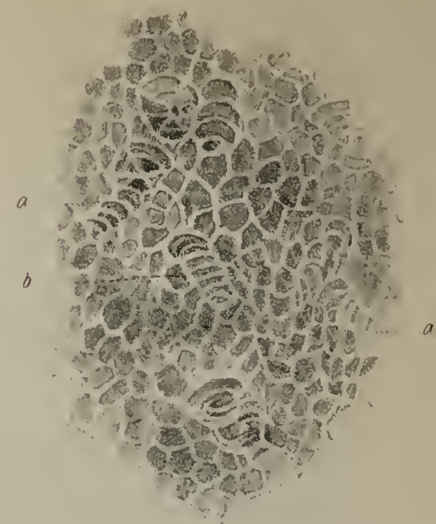


Fig. 4.

Fig. 5.

Fig. 6.

Fig. 7.

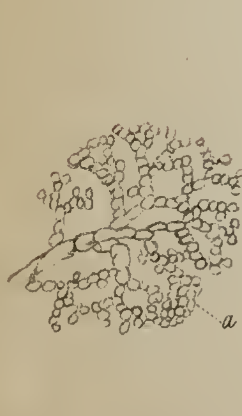
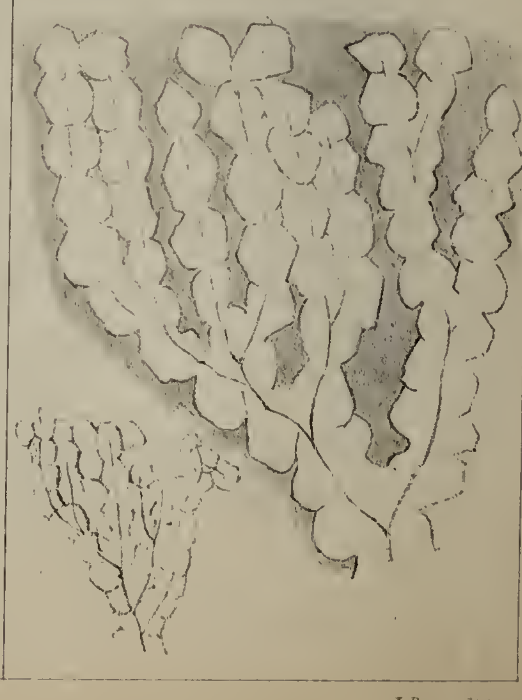


Fig. 8.

Fig. 9.



J. Basire, lith.

youth and the large cells of old age, I found them varying from $\frac{1}{200}$th to $\frac{1}{500}$th of an inch; the largest oval foramina were from $\frac{1}{60}$th to $\frac{1}{80}$th of an inch, some were from $\frac{1}{100}$th to $\frac{1}{150}$th of an inch, and there were others less. In dried and inflated preparations, the cells and foramina being fully distended with air, measure more than when the preparations are fresh and recent. On the other hand, in injected preparations, the vessels being distended, the cells and foramina measure less.

Explanation of the Plate.

PLATE XII.

Fig. 1. A thin section of dried and inflated lung, showing large oval foramina produced by dividing the lobular passages; (*b*, *b*) several oval foramina close together, the section having passed very near to the point whence the passages branch off. Subjacent cells and foramina are seen by looking down through the uppermost foramina (*c*, *c*).

Fig. 2. Oval foramina seen in a section of inflated and dried lung made at the surface and including the pleura; they are somewhat smaller, and placed at more equal distances from each other than in the preceding figure.

Fig. 3. A thin section of recent and macerated lung, slightly extended, showing sections of cells and lobular passages; (*a*, *a*, *b*) a series of communicating cells.

Fig. 4. A small portion of the thin edge of a lung of a Rabbit injected partially with mercury, showing a mass of minute globules in a fully injected lobule (*a*), and nodulated or beaded branches in others (*b*). The nodules being cells communicating with each other by lobular passages; the branched symmetry is lost in a mass of globules at *c*.

Figs. 5 and 6. Small sections from the thin margin of the lung of a fœtal Calf, magnified about three diameters. The lobules are compressed and spread out by pressure between two plates of glass. Several bronchial tubes are filled with mercury; they *gradually* assume a nodulated appearance, and at length in the interior of the lobules terminate in cells and lobular passages.

Fig. 7. A more magnified view of the branchings of the intralobular bronchial ramifications. The mercury has been urged on by increased pressure, so as to fill a greater number of ramifications, which at (*a*) have become so numerous that their symmetry is lost in the multitude of globules.

Fig. 8. Intralobular bronchial ramifications, partially inflated and highly magnified. (*a*). *Culs de sac* terminations lying against the lateral inflations of adjoining branches. (*b*, *b*, *c*). The multilocular *culs de sac* at the surface of a lobule.

Fig. 9. Shows the cells formed upon the intralobular bronchial branches, with polyhedric figures formed by pressure.

X. *On the specific Inductive Capacities of certain Electrical Substances.*

By W. Snow Harris, *Esq., F.R.S., &c.*

Received May 21,—Read June 9, 1842.

1. THE unrivalled series of Researches in Electricity with which Dr. Faraday has enriched the pages of the Royal Society's Transactions, have greatly extended our field of view in this wonderful department of natural knowledge.

The doctrine of specific inductive capacity advanced in these profound researches, has very considerable claim to attention, being both a novel and important feature of electrical action. I have been hence led to some further examination of it, and, from the results obtained, I am not without hope that a brief account of them may be worthy the notice of the Royal Society.

2. If a given measured quantity of electricity be deposited on different insulating substances of the same thickness, and having metallic coatings of the same extent, the intensity of the charge, as shown by an electrometer, will greatly vary. I found the differences in some cases to be so great as twenty-five to one. Thus, in one instance, the intensity of the charge sustained by induction through air being 25°, the intensity of the same charge sustained by induction through lac only amounted to 1°.

An experimental examination of this question, however, demands very considerable caution, since a small degree of conducting power, or dissipation of the charge, or a partial absorption of electricity by the superficial particles of a given substance, would at once diminish the apparent intensity; whilst, on the other hand, any subsequent evolution of the quantity absorbed would, if added to the quantity subsequently deposited, tend to increase it. It is hence essential that experimental processes for the detection and measurement of specific induction should be such as to admit of being carried out in the least possible time under conditions of very perfect insulation.

3. Such processes I have endeavoured to supply in the following experimental examination of this interesting subject; they may be thus briefly stated.

The given substance to be examined being cast into a circular plate of a foot in diameter and four-tenths of an inch thick, by means of a mould formed of two pieces of polished marble, and an intermediate ring of brass, coatings of tin foil six inches in diameter were applied to each of its surfaces, so as to leave an insulating edge of three inches wide. Plate XIII. fig. 1. represents a plate thus prepared, in which *a b* is the plate, and *c* the central coating. When a dielectric medium of air was required, the opposed coatings were made of wood, about three-tenths of an inch in thickness, covered with tin foil; and were fixed at the given distance by

means of three small supports of shell-lac, cemented to the circumferences, as represented by fig. 2, in which *c d* represent the coatings, and *a b* two of the shell-lac supports. In some instances the plates were opposed to each other at the extremities of insulating rods of glass, as represented in fig. 8. Plate IV. of the Philosophical Transactions for 1839.

4. Fluid dielectric media were examined by means of the arrangement represented in fig. 3, in which *m n* is a sort of glass bowl having a contracted opening and neck at *h*. This opening is closed by a fine piece of cork, so as to admit of a conducting wire *i* passing through it fluid tight; *c d* are the circular coatings just described, the under one, *d*, being screwed on the end of the wire *i*. The whole is supported on a convenient open frame; and the fluid to be examined is poured into the glass bowl, so as to completely surround and fill the space between the circular metallic surfaces *c d*. An inverted lamp glass shade may be employed with advantage for this purpose.

5. It will be immediately seen that if under any of these conditions one of the coatings, *c*, fig. 4, be connected with the disc *m* of the electrometer E*, we may determine by an easy and direct experiment, the three following elements necessary for the elucidation of the question under consideration. First. If we insulate the whole system on a glass rod *k*, and deposit a given measured quantity of electricity on the coating *c*, we may determine the intensity of that quantity as expressed by the electrometer, taking the whole as free charge. Secondly. By connecting the under plate *d* with the electrometer, and charging the upper plate *c* with a given measured quantity, we may determine in a similar way the direct induction between the plates in degrees of intensity, or free charge shown by the electrometer. Thirdly. By connecting the under coating *d* with the ground, and charging the superior plate *c* with a given measured quantity, we may determine in degrees of the electrometer the proportion of the charge uncondensed by the uninsulated plate *d*, that is to say, we may measure the intensity of the charge under the ordinary conditions of the Leyden experiment. In this way, as is evident, we may examine any dielectric medium, whether solid, fluid or gaseous, contained between the metallic coatings *c*, *d*, and compare their respective influences over the degree of induction which takes place through them, between the coatings *c*, *d*.

6. I have called the degree of intensity expressed in terms of the electrometer, *free charge*, for the sake of perspicuity, and in order to distinguish that portion of the charge, whatever it be, which is active on the electrometer, from that portion which is condensed by induction. For similar reasons I have called the action of the charged on the neutral plate, *direct induction*, in contradistinction to the condensing action of the neutral on the charged plate, which I term the *reflected*, or *indirect induction*. It must, however, be understood that these terms are merely employed as expressing conveniently the different actions to which I shall have occasion to refer, and that they are limited to the definitions just given†.

* This instrument is described in the Philosophical Transactions for 1839, Part II. p. 215.

† Philosophical Transactions for 1829, p. 219.

7. In order to obtain a given measured charge, sparks were taken upon insulated metallic carrier plates A, A′, fig. 5 and 6, from the knob of a jar K, fig. 7, charged to a given intensity, and the electricity was deposited on the coating *c*, fig. 4. But as the repeated transfer of one plate, considered as a unit of charge, would be attended by a loss of electricity upon a great number of measures, in consequence of some residuary electricity being again brought off at each contact, I employed larger carrier plates, A, fig. 5, which could at once take up, under the same intensity, double, triple, &c. the quantity contained on the smaller one, A, fig. 5, and thus deposit at once, together with the plate, a given number of measures on the coated substance *c**.

8. I found it, however, desirable in some cases to observe the intensity of the half or quarter of the charge collected on the large transfer plate A, fig. 5, by dividing and subdividing it with a second equal and similar neutral plate B, fig. 8. Thus, supposing the whole disc to contain under a given intensity a quantity equal to eight measures, we may immediately obtain four measures by a momentary contact with an insulated neutral and similar plate B, fig. 8, and two measures by a second contact. We are thus enabled to work with lower charges in certain cases; since from the intensity of the half, or quarter of a charge, we can, by known laws of electrical action, deduce the intensity of the whole. We avoid in this way the dissipation which is liable to occur under a high intensity, and hence arrive at a more correct result. The carrier plates employed were of various kinds, and were constructed either of metallic substances or of gilded wood, and were insulated on very long slender rods of glass covered with lac, as represented in figs. 5 and 6.

9. The jar K, fig. 7, is supported on a varnished glass rod K; it contains about 100 square inches of coating, and was charged with fifteen measures of a small unit jar, containing about ten square inches, the measuring balls being set at ·2 of an inch apart. When charged, it was removed from the machine, and the connection of the outer coating with the ground withdrawn, so as to leave it well insulated. As often as a charge was drawn from the knob by either of the carrier plates A, A′, an equivalent charge was communicated to the outer or negative coating, and thus repeated measured charges of the same intensity were obtained. The state of this jar was examined from time to time by means of a small carrier plate of three inches in diameter, and a second electrometer E′, fig. 9. As long as the jar could charge this plate to an intensity of 10°, as measured by the electrometer, the discs *m*, *n*, fig. 9, being at a given distance, so long it was deemed in a fit state for experiment. When the intensity fell below this point, the original charge of fifteen unit measures was again restored.

10. The electrometer E, fig. 4, has been fully described in the Philosophical Transactions for 1839†; it is therefore only requisite to state, that by means of a hydrostatic counterpoise *v*, acting over a delicately hung wheel W, we obtain a continued and uniform balance to the attractive force between the opposed discs *f*, *m*, ope-

* Philosophical Transactions for 1834, p. 235. † p. 215.

rating on the opposite arm of the wheel; whilst an index *i o* attached to the wheel registers the force in degrees of a graduated arc *x o y*.

11. These preliminary explanations being understood, the following experiments will be fully comprehended.

Exp. 1. A circular coated plate of shell-lac, N, fig. 4, being placed on the insulated rod *k*, and its upper coating *c* connected with the electrometer disc *m*, one measure of electricity was deposited on it, by placing one of the small charged carrier discs immediately on the coating. In order to find the intensity by the electrometer at a constant distance of ·5 of an inch between the attracting discs *m*, *f*, and to which they had been previously adjusted when the index was at zero, the hydrostatic counterpoise was lowered by means of the screw S until the index was again brought to zero of the arc; whatever force, therefore, was now operating between the discs *m*, *f*, was operating at the given distance of ·5 of an inch. To find this force in degrees, the deposited electricity was discharged; the index then declined or fell back in the direction *o y*, a certain number of degrees, showing the force or intensity required.

Thus the deposition of one measure on the insulated plate *c* evinced an intensity of 4°, and according to the known law of accumulation two measures evinced an intensity of 16°, and so on, as the square of the quantity deposited* up to the limit of charge. Now this intensity was found to be the same, or nearly so, with every insulating substance tried, whether shell-lac, or air, or brimstone, or any other good insulator, and was very little different whether insulated as a single plate or as a double plate, such as represented in fig. 2. An intensity of 4° was therefore taken as the free charge, and as indicating one measure, supposing it all active on the electrometer, and uncondensed by induction through any given medium.

Exp. 2. The under coating *d* being now connected with the electrometer disc *m*, and 1, 2, 3, &c. measures successively deposited on the coating *c*, the respective intensities developed in the opposite coating *d* by induction were, for one measure 3°, two measures 12°, three measures 27°, and so on up to the limit of inductive development in the opposed plate†.

12. Now this direct induction was observed to be the same, or very nearly so, whether operating through air or through lac, or any other solid insulator; thus confirming, together with the preceding experiment, Dr. Faraday's observation relative to shell-lac (1255.), viz. "That its solid condition enabled it to retain the excited particles in a permanent position, but that appeared to be all, for these particles acted just as freely through the shell-lac on one side as through the air on the other." He did not find, however, every substance bear a rigid examination in this respect; yet the substances which I have tested all evinced nearly the same freedom, as measurable by the charges and electrometer employed.

Exp. 3. The under coating *d*, fig. 4, being connected with the ground, and the

* Philosophical Transactions for 1834, p. 219 and 221. † Ibid. 1839, p. 223 and 224.

upper coating c with the electrometer, a quantity equal to five measures was deposited on it, and the intensity taken under the common conditions of the LEYDEN experiment. In this case, however, the intensities varied considerably, being different with each substance, as shown in the following Table:—

TABLE I.

Showing the Intensity of five measures of electricity in degrees of the Electrometer when accumulated as a charge on different coated Electrics.

Substance.	Lac.	Brimstone.	Best Flint Glass.	Bees' wax.	Pitch.	Rosin.	Air.
Intensity. .	2°	$2^\circ{\cdot}25$	$2^\circ{\cdot}5$	$3^\circ{\cdot}25$	4°	5°	32°

When ten measures were deposited, the intensities were found to increase as the square of the quantity, according to the law already referred to (11.); so that with ten measures the small differences were more marked.

13. It is not difficult to discover from these intensities the indirect induction or specific inductive capacities of the various substances to which they refer, since their respective influences over the amount of induction which takes place through them, may be conceived to vary with the quantity of electricity condensed, as it were, by the uninsulated coating, and thus rendered insensible to the electrometer.

Now, by the known laws of the electrometer*, the intensity of the charged side is proportional to the square of the quantity which the free coating ceases to hold in equilibrio; we may therefore find this quantity, and having deducted it from the whole quantity of charge, the remainder may be taken to represent the inductive capacity of the substance under examination.

Thus, to find the inductive capacity of lac with reference to five measures by Table I., we have to find the free quantity corresponding to an intensity of 2°. But the intensity corresponding to one measure, taken as a free quantity, is 4° (Exp. 1.). Taking then the quantities as the square roots of the intensities, we obtain ·7 of a measure nearly for an intensity of 2°, which is the uncondensed part of the charge†. If, therefore, we subtract this from five, the whole number of charges, we have 4·3 for the indirect induction, or specific inductive capacity of lac. In a similar way we find the relative specific inductive capacity of air to be 2·2, of pitch 4, and so on, as in the following Table.

* Philosophical Transactions for 1839, p. 237.

† Or by the laws of the electrometer, we have in taking the forces as the square of the quantity $4^\circ : 2^\circ :: 1^2 : x^2$ or $4\,x^2 = 2$, and $x = \sqrt{\cdot 5} = \cdot 7$ nearly for the quantity corresponding to 2° when the quantity corresponding to 4° is unity.

Table II.

Showing the Specific Inductive Capacities of various Electrical Bodies in terms of the number of measures condensed by them on an accumulation of five measures.

Substances.	Lac.	Brimstone.	Flint glass.	Bees' wax.	Pitch.	Rosin.	Air.
Inductive capacity	4·3	4·25	4·21	4·1	4	3·9	2·2

14. If, then, as in the preceding Table, the number of charges condensed by the indirect induction of the uninsulated coating be taken to express the respective influences of different dielectric substances over the induction through them, we have the relative inductive capacities as in the following Table.

Table III.

Showing the Inductive Capacities of various dielectric Bodies in relation to Air taken as unity.

Substances.	Air.	Rosin.	Pitch.	Bees' wax.	Glass.	Brimstone.	Lac.
Relative capacity	1	1·77	1·8	1·86	1·9	1·93	1·95

The results in the case of lac and air very nearly coincide with those arrived at by Dr. Faraday, who found (1270.) the relation of lac to air as 2 : 1, or very nearly, which is about the proportion deduced in the above Table. He also found a very high inductive capacity for sulphur, which is likewise the case in the above Table, although the specimen employed in these experiments did not give a higher capacity than lac, as appeared to be the case in the experiment Dr. Faraday refers to (1275.), and which he considers unexceptionable. With respect to glass and the other substances above given, all the specimens insulated well, and charged and discharged freely in the usual way. The experiments were certainly uninfluenced by the sources of error above-mentioned (2.), since the intensity varied with the square of the number of charges deposited on the insulated coating, and the general laws of electrical accumulation on coated surfaces were manifested by them, which could not have been the case under a sensible degree of conducting power, or a partial absorption of electricity by their superficial particles. Thus I found a square of thick plate glass of the common kind, and which the Lords Commissioners of the Admiralty very kindly permitted me to purchase from the stores of Her Majesty's Dock Yard, quite unfit for these investigations. It would not take the slightest degree of charge under any condition under which I could place it. By covering its exposed edges with shell-lac dissolved in naphtha or alcohol, I succeeded in rendering it non-conducting on the surface, but still it would not assume the charged state in any degree. I tried other specimens of plate glass, and with nearly the same result. And it was not

until I tried a small bowl of the best flint glass that I could succeed in obtaining anything like a comparative experiment. This bowl, however, which fortunately was of the same thickness, or very nearly so, as the other substances tried, charged very freely when six inches of coating were given to it, as in the other cases, and evinced a high inductive capacity.

15. With respect to fluid dielectric bodies, although I have thought it worth while to advert briefly to the method I employed in subjecting them to experiment, yet I am obliged to admit that it was attended by no positive result whatever. I found all the fluid bodies I examined, viz. oil of turpentine, common oil, naphtha, &c., quite incapable of assuming the charged state, or at least if they did so, it became instantly destroyed. I could not hence arrive at any conclusion relative to their capacities for sustaining electrical induction, and in this failure I am not alone. Faraday found, not only these, but a great many solid bodies quite unfit for experiment on account of their incapacity to sustain a sufficient charge (1279.) (1280.). That this incapacity is not dependent on the fluid condition of the body is quite evident, since the thick plate of glass just mentioned equally failed in its power of receiving a charge. I am however not without hopes, that by varying the temperature of these substances, or by another form of experiment, or otherwise by a more complete preparation of them, their inductive capacities, however low, may be relatively discovered.

16. I have now merely to offer, in conclusion, a few observations on the experimental processes which have been employed in the above investigation. First, it is essential that the substances to be examined should have perfect solidity, and be well and evenly cast, so as not to present any small fissures or cracks. The coatings should be closely attached to their surfaces by a little stout paste, and well rubbed over, in order to completely exclude the particles of air, which otherwise are liable to detach the coating from the surface, and vitiate the experiment. When a substance thus coated charges and discharges freely, and on being charged with 1, 2, 3, &c. measures successively, evinces by the electrometer intensities which are as the squares of these quantities, it may be taken as being in a fit state for experiment on its inductive capacity. Secondly, to avoid dissipation or loss from charges which with some substances evince a high intensity, it is desirable to work with one half or one quarter the whole charge in such cases, and deduce the comparative intensity from these. Thus in comparing shell-lac and air, we find that a quantity which with shell-lac only affects the electrometer by 1°, will with air as the dielectric medium affect the electrometer 25°; and as it is most important to obtain the full measure of induction through air, it is safer in certain cases to find the intensity of half the quantity, and then by the law of the intensity which is as the square of the quantity, deduce the intensity due to the full charge. If we required, for example, to compare the result of twenty measures on shell-lac with twenty measures on air, and that the intensity of twenty measures on air was so great as to cause dissipation between the plates,

we may readily determine the full intensity by dividing the charge (8.) and operating with ten measures. Suppose the ten measures evinced an intensity of 15°, then the intensity due to twenty measures would be 60°, being as Q^2. We more particularly require this, because the full twenty measures would be necessary for the shell-lac in order to obtain a decided result, which at the greatest might not exceed in this case 4°.

Lastly, it is essential to manipulate under a good insulating air, in a dry room and with every convenience at hand for warming and thoroughly drying from time to time the various insulators, which is best done by means of small heated irons curved into half cylinders, and fixed in convenient handles. If these precautions be attended to, the electrometers will remain without dissipation for twice or thrice the time requisite for the experiment, and the result will be found very uniform and invariable.

Plymouth,
May 1, 1842.

XI. *An Appendix to a Paper on the Nervous Ganglia of the Uterus, with a further Account of the Nervous Structures of that Organ. By* Robert Lee, *M.D., F.R.S., Coll. Reg. Med. Socius.*

Received June 16,—Read June 16, 1842.

FROM the functions of the human uterus, Galen inferred that it must be supplied with nerves, but there is no evidence to prove that Galen, or any of the celebrated anatomists who flourished before the middle of the eighteenth century, ever traced the great sympathetic and sacral nerves into the uterus, or discovered that its nerves enlarge during pregnancy. This was first done by Dr. W. Hunter, who describes the hypogastric nerve on each side as passing to the gravid uterus, behind the hypogastric vessels, and spreading out in branches like the portio dura of the seventh pair, or like the sticks of a fan, with many communications over the whole side of the uterus and vagina. As Dr. Hunter never examined the nerves of the unimpregnated uterus, and saw the nerves of the gravid uterus dissected only in one subject, he did not certainly know that they increased after conception. "I cannot," he observes, "take upon me to say what change happens to the system of uterine nerves from utero-gestation, but I suspect them to be enlarged in proportion as the vessels*."

Mr. John Hunter denied that the nerves of the uterus ever enlarged during pregnancy. "The uterus in the time of pregnancy," he says, "increases in substance and size, probably fifty times beyond what it naturally is, and yet we find that the nerves of this part are not in the smallest degree increased. This shows that the brain and nerves have nothing to do with the actions of a part, while the vessels which are evident increase in proportion to the increased size; if the same had taken place with the nerves, we should have reasoned from analogy†." Dr. William Hunter left no preparations of the nerves of the uterus, nor did Mr. J. Hunter, in support of their conflicting statements, and at the beginning of the year 1838 I believe there were no preparations in this country, showing the nerves of the uterus dissected, either in the unimpregnated or gravid state. Sir Astley Cooper then maintained, that it was impossible for the nerves of the uterus, or the nerves of any other organ, to increase under any circumstances.

In 1822 Professor Tiedemann published a description of the nerves of the uterus with two engravings. In the first, the spermatic nerves are represented on both sides accompanying the spermatic arteries to the ovaria. The spermatic veins, and the

* An Anatomical Description of the Human Gravid Uterus. Lond. 1794, p. 21.

† The works of J. Hunter, vol. iii. p. 117. A.D. 1837.

nerves which followed them, are not seen. A few small branches of nerves from the hypogastric plexus are seen ramifying on the posterior and inferior surface of the uterus with the uterine arteries. The whole of the superior part of the uterus is covered with peritoneum. In the second Plate some small branches from the left hypogastric nerve, before it enters the great ganglion at the cervix, are seen accompanying the left uterine artery on the left side of the lower part of the uterus. From Professor Tiedemann's work it might justly be inferred, that the human gravid uterus is more sparingly supplied with nerves than any other organ in the body*.

In 1823 Professor Lobstein stated that the uterus before and after conception had a very scanty supply of nerves, "Rarissime in uteri substantiam tum vacui tum gravidi sese immittere videntur nervorum surculi†."

In 1829 Professor Osiander affirmed that the nerves of the human uterus had never been seen, either by himself or by any other anatomist, and that he had been deceived by the authority of scientific persons, when he stated that nerves were spread over the whole uterus.

On the 8th of April, 1838, while dissecting a gravid uterus of seven months, I accidentally observed the trunk of a large nerve proceeding upward from the cervix to the body of the uterus along with the right uterine vein, and sending off branches in its course to the posterior surface of the uterus, some of which accompanied the ramifications of the vein, and others were inserted into the peritoneum. A broad band, resembling a plexus of nerves, was seen extending across the posterior surface of the uterus, and covering the nerve midway between the fundus and the cervix. On the left side the same appearances were seen, and several branches of the nerves accompanying the uterine vein were distinctly continuous with branches of the great plexus crossing the body of the uterus. The preparation was placed in the museum of St. George's Hospital on the 1st of October, 1838. Several eminent anatomists, to whom I showed the preparation, thought that I had been misled by appearances, and that they were absorbent vessels accompanying the veins and tendinous fibres, spread across the posterior surface of the uterus. They all acknowledged that they had never seen nor dissected the nerves of the uterus, either in the human subject or in any of the lower animals. I resolved, when another opportunity should present, to follow the sympathetic into the gravid uterus, with the utmost care, that I might discover, if possible, the nature of the great plexuses covering its surface.

On the 18th of December, 1838, a woman in the sixth month of pregnancy died in St. George's Hospital, a few hours after the fœtus and its appendages had been expelled; the uterus was removed with all its blood-vessels and nerves remaining connected with it, and the great sympathetic and sacral nerves were traced to the different parts of the uterus, while the preparation was under alcohol.

In a communication to this Society, which was read on the 12th of December, 1839,

* Tabulæ Nervorum Uteri, fol. Heidelbergæ, 1822.

† De Nervi Sympathetica Humani Fabrica, &c. Paris, 1823, p. 31.

I described the appearances displayed in these dissections, and represented by figures the spermatic, hypogastric, and sacral nerves passing into four great plexuses under the peritoneum of the body of the uterus. From the form, colour, vascularity, and general distribution of these plexuses, and from their branches actually coalescing with those of the great sympathetic, I inferred that they were true nervous ganglionic plexuses, and formed the nervous system of the uterus. Some anatomists of reputation formed a different opinion, and concluded that they were nothing but bands of elastic tissue, gelatinous tissue, or cellular membrane connecting the peritoneum with the muscular coat of the uterus. All who examined the dissections admitted that the plexuses were accompanied with arteries, and were continuous with the spermatic and hypogastric nerves. None attempted to show in any other part of the body, bands of elastic tissue assuming a similar plexiform appearance, accompanied with arteries or continuous with nerves. The communication was withdrawn from the Royal Society.

I continued the investigation of this subject during the whole of 1840 and 1841, and discovered the great nervous ganglia at the neck of the uterus, a description of which is contained in the last volume of the Philosophical Transactions. But these ganglia, which exceed in size the semilunar ganglia of the great sympathetic, constitute only a small portion of the nervous system of the human uterus. I propose now briefly to describe other nervous structures of far greater size, as displayed in the dissection of a gravid uterus at the end of the ninth month of pregnancy.

In this preparation the great sympathetic nerve sends numerous branches from both its cords to the trunk of the inferior mesenteric artery, which form a great plexus around it. These nerves accompany all the ramifications of the artery, but the greater number proceed with the hemorrhoidal artery to the rectum. The two cords of the great sympathetic, after giving off these branches to the inferior mesenteric artery, pass down before the aorta nearly two inches below its bifurcation, where they are united by several fine nervous filaments. But the cords continue distinct, and soon separating, each passes down behind the hypogastric blood-vessels to the side of the neck of the uterus, and there terminates in the corresponding hypogastric or utero-cervical ganglion. The left cord of the great sympathetic, or as it is usually called, the hypogastric nerve, enlarges greatly as it approaches the hypogastric ganglion. This ganglion is nearly two inches in breadth, and covers a great part of the cervix uteri. It appears to consist of six or seven smaller ganglia, which are united together by nervous cords. Each of these ganglia is a thick solid nervous mass, of an orange white colour inclined to brown. Arteries which have been injected pass through these smaller ganglia and accompany the various nervous filaments which proceed from them. Into the whole outer surface of the left hypogastric ganglion, numerous branches from the third sacral nerve enter; and behind there is a great connection formed between the ganglion and the branches of the left hemorrhoidal nerve. The vaginal nerves arise from the inferior margin of the ganglion, and the vesical from its anterior border. Some of these nerves pass on the outside of the

ureter to enter the middle vesical ganglion, and others pass on the inner surface of the ureter to the anterior part of the neck of the uterus.

From the superior and anterior part of the left hypogastric ganglion, a plexus of nerves accompanied by an injected tortuous artery, proceeds upward along the whole body of the uterus, near the left side, to the trunk of the left spermatic vein, and there terminates in a dense, reddish brown coloured mass, consisting of fibres firmly interlaced together, and which has all the characters of a true nervous ganglion. From its vicinity to the principal spermatic artery and vein which it partly surrounds, and the ligament of the ovary, it may be called the *left spermatic ganglion.* Between this ganglion and the left hypogastric ganglion, an artery extends which is closely embraced by a plexus of nerves, and a direct nervous communication is thus established between these remote ganglia. The nerves adhered so firmly to the artery through its whole course, that before they were separated they presented the appearance of two white lines on its sides, with filaments crossing over the vessel. From these nerves extending between the left hypogastric and spermatic ganglion, branches with arteries are given off in their whole course to the *subperitoneal ganglia* and *plexuses* on the posterior surface of the uterus, and also branches to the plexuses on the anterior surface. On approaching the spermatic ganglion, these nerves with their artery pass under or between the branches of the *left subperitoneal plexuses* and frequently communicate with them by fine nervous filaments. The artery can be readily traced through the substance of the spermatic ganglion, but the nerves which accompany it from the hypogastric ganglion, immediately disappear on entering the mass. Numerous large branches of nerves from the left subperitoneal plexus likewise terminate in the left spermatic ganglion, but some of them pass under it, and proceed to the round ligament; and others are continued upward, gradually diminishing in size as they approach the renal plexus along the spermatic bloodvessels. From the upper border of this ganglion, large flat nerves proceed to ramify on the fundus uteri, and pass with the vessels into the muscular coat. The trunk of the spermatic vein and artery is almost completely surrounded with this ganglion, as the trunks of the uterine, and vaginal arteries and veins are inclosed within rings of nerve connected with the hypogastric ganglion.

In this dissection there are nervous structures displayed on the anterior and posterior surfaces of the uterus of still greater magnitude. These, from their situation, may be called the *subperitoneal ganglia* and *plexuses* of the uterus.

Over the middle of the lower part of the body of the uterus behind, immediately beneath the peritoneum, is situated the posterior subperitoneal ganglion, which is considerably larger than the left hypogastric ganglion. It presents the appearance of a layer of dense structure composed of fibres strongly interlaced together, having a yellowish brown colour. It adheres firmly to the peritoneum, but between its lower surface and the muscular coat of the uterus, there is interposed a thick soft layer of cellular substance, through which filaments of nerves and branches of con-

siderable size pass to the muscular coat of the uterus. The middle part of the ganglion is more than two lines in thickness, but it becomes everywhere thinner towards the circumference, and particularly at the inferior border, where it sends off many nerves to the back part of the vagina. From its left lower and lateral part, it sends off two layers of broad nerves, one of which adheres to the peritoneum, and the other closely invests the muscular coat and blood-vessels of the uterus. Between these layers there is placed a very thick mass of soft cellular membrane, through which innumerable branches of nerves pass between these layers, the hypogastric ganglion, and the plexus of nerves with the injected artery extending between the hypogastric and spermatic ganglia. Many of the superficial nerves pass down under the peritoneum, and terminate in the upper border of the left hypogastric ganglion, and upon these superficial nerves there is formed another ganglion of considerable size, between which and the hypogastric nerve numerous branches of soft nerves extend. This ganglion formed on the nerves under the peritoneum near the edge of the uterus, is thick and solid, and consists of a yellowish brown substance, with white nervous filaments interlaced, and arteries of considerable size passing through it. From its lower border large nerves extend to the upper edge of the hypogastric ganglion, and innumerable soft nerves enter the whole inner surface of the hypogastric ganglion, which take their origin from the lower part of the great subperitoneal ganglion. The upper part of this ganglion becomes firmly adherent both to the peritoneum and muscular coat of the uterus, which it covers as high as the fundus. Large broad nervous plexuses, superficial and deep, extend from the upper portion of the subperitoneal ganglion across the body of the uterus to the spermatic ganglion, and blood-vessels, and the round ligament, around which they form a sheath of nerves.

In an elaborate drawing by Mr. Joseph Perry, all the ganglia and plexuses on the left side of the uterus now described, have been represented with the greatest fidelity.

As the arteries and veins on the right side of the uterus are only partially injected, the nerves extending between the hypogastric and spermatic ganglia have not been so minutely traced. But that there is a similar nervous chain connecting these great ganglia of the fundus and cervix and the subperitoneal ganglia and plexuses, does not admit of doubt, and has been clearly demonstrated by other dissections at an earlier period of pregnancy.

Over the middle of the anterior and lower part of the body of the uterus, there is situated a nervous and vascular mass, of great extent, and similar in structure to the subperitoneal ganglia described on the posterior surface. It adheres to the peritoneum firmly, but on being divided longitudinally, it is also observed to be separated from the muscular coat of the uterus by a soft stratum of cellular membrane. From the lower part of this *anterior subperitoneal ganglion* nerves are sent down to the cervix uteri and vagina, and numerous branches pass off on both sides to the hypogastric ganglia. Superficial and deep plexuses of nerves are likewise sent off from its superior lateral borders, which proceed across the uterus, sending branches into

the muscular coat, and uniting with all the ganglionic plexuses on the posterior surface. The appearances presented by the anterior subperitoneal ganglia and plexuses in the fourth month of pregnancy, have been displayed in the second engraving which illustrated the paper on the nervous ganglia of the uterus. At that period the ganglion seemed nothing but a thin nervous and vascular membrane, imbedded in soft cellular substance, through which the delicate nervous filaments accompanied with arteries proceeded to the superior angles of the uterus. On comparing this dissection with that now described, it is impossible to avoid being struck with the enormous development of these nervous structures during the four latter months of pregnancy, or to resist the conclusion that these are formed for the purpose of supplying the uterus with that nervous power which it requires during labour.

These dissections prove that the human uterus possesses a great system of nerves, which enlarges with the coats, blood-vessels and absorbents during pregnancy, and which returns after parturition to its original condition before conception takes place. It is chiefly by the influence of these nerves, that the uterus performs the varied functions of menstruation, conception, and parturition, and it is solely by their means, that the whole fabric of the nervous system sympathises with the different morbid affections of the uterus. If these nerves of the uterus could not be demonstrated, its physiology and pathology would be completely inexplicable.

Explanation of the Plate.

PLATE XIV.

Exhibits the ganglia and nerves on the posterior and left side of the gravid uterus at the end of the ninth month of pregnancy.

A. The fundus and body of the uterus, having the peritoneum dissected off from the left side.

B. The vagina covered with nerves proceeding from the inferior border of the left hypogastric ganglion.

C. The rectum.

D. The left ovarium and Fallopian tube.

E. The trunk of the left spermatic vein and artery surrounded by the left spermatic ganglion.

F. The aorta divided a little above the origin of the right spermatic artery, and about three inches above its division into the two common iliac arteries.

G. The vena cava.

H. Trunk of the right spermatic vein entering the vena cava.

I. Right ureter.

K. The two cords of the great sympathetic nerve passing down along the front of the aorta.

Joseph Perry del. 1842.

L. Trunk of the inferior mesenteric artery passing off from the aorta, and covered with a great plexus of nerves sent off from the left and right cords of the great sympathetic.

M. M. The two cords of the great sympathetic passing down below the bifurcation of the aorta to the point where they separate into the right and left hypogastric nerves.

N. The right hypogastric nerve with its artery injected proceeding to the neck of the uterus, to terminate in the right hypogastric ganglion.

O. The left hypogastric nerve where it is entering the left hypogastric ganglion and giving off branches to the left subperitoneal ganglion.

P. Hemorrhoidal nerves accompanying the hemorrhoidal artery and proceeding from the great plexus which surrounded the inferior mesenteric artery.

Q. The sacral nerves entering the whole outer surface of the hypogastric ganglion.

R. The left hypogastric ganglion with its arteries injected.

S. The nerves of the vagina.

T. Nerves with an injected artery proceeding from the upper part of the left hypogastric ganglion along the body of the uterus, and terminating in the left spermatic ganglion.

U. Continuation of these nerves and the branches which they give off to the subperitoneal plexuses.

V. The same nerves passing upward beneath the subperitoneal plexuses, and anastomosing freely with them.

W. The left spermatic ganglion, in which the nerves and artery from the hypogastric ganglion, and the branches of the left subperitoneal plexuses terminate, and from which the nerves of the fundus uteri are supplied.

X. The left subperitoneal plexuses covering the body of the uterus.

Y. The left subperitoneal ganglion with numerous branches of nerves extending between it and the left hypogastric nerve and ganglion.

Z. The left common iliac artery cut across and turned aside, that the left hypogastric nerve and ganglion might be traced and exposed.

XII. *On the Action of the Rays of the Solar Spectrum on Vegetable Colours, and on some new Photographic Processes. By Sir* John F. W. Herschel, *Bart. K.H. F.R.S.*

Received June 15,—Read June 16, 1842.

149*. In my paper on the "Chemical Action of the Solar Spectrum on preparations of Silver and other substances," read to the Royal Society in February 1840, and of which the present communication is intended as a continuation or supplement, some experiments on the effect of the spectrum on the colouring matter of the *Viola tricolor*, and on the resin of guaiacum are described, which the extreme deficiency of sunshine during the summer and autumn of the year 1839 prevented me from prosecuting efficiently up to the date of that communication. The ensuing year 1840 was quite as remarkable for an excess of sunshine as its predecessor for the reverse. Unfortunately the derangements consequent on a change of residence prevented my availing myself of that most favourable conjuncture, and it was not till the autumn of that year that the inquiry could be resumed. From that time to the present date it has been prosecuted at intervals as the weather would allow, though owing to the almost unprecedented continuance of bad weather during the whole of the past summer and autumn (1841), it has of late been almost wholly suspended†. In photographic processes, where silver and other metals are used, the effect of light is so rapid that the state of the weather, as to gloom or sunshine, is of little moment. It is otherwise in the class of photographic actions now to be considered, in which exposure to the concentrated spectrum for many hours, to clear sunshine for several days, or to dispersed light for whole months, is requisite to bring on many of the effects described, and those some of the most curious. Moreover, in such experiments, when unduly prolonged by bad weather, the effects due to the action of light become mixed and confounded with those of spontaneous changes in the organic substances employed, arising from the influence of air, and especially of moisture, &c., and so give rise to contradictory conclusions, or at all events preclude definite results, and obscure the perception of characters which might serve as guides in an intricate inquiry, and afford hints for the conduct of future experiment. It is owing to these causes that I am unable to present the results at which I have arrived, in any sort of regular or systematic connection; nor should I have ventured to present them at all to the Royal Society, but in the hope that, desultory as they are, there may yet be

* The paragraphs, for convenience of reference, are numbered in continuation of those of the previous paper referred to in the text.

† This was written in April 1842, since which a repetition of the season of 1840 seems to have commenced.

found in them matter of sufficient interest to render their longer suppression unadvisable, and to induce others more favourably situated as to climate, to prosecute the subject.

150. The materials operated on in these experiments have been for the most part the juices of the flowers or leaves of plants, expressed, either simply, or with addition of alcohol, or under the influence of other chemical reagents. Some few resinous and dyeing substances have also been subjected to experiment, but with less perseverance than the obvious practical importance of this branch of the subject might demand, except in the case of guaiacum, whose relations to light, heat, and chemical agents are exceedingly remarkable and instructive, for which reason, as well as because some of these relations have been treated of in my former paper, I shall commence the account of my later experiments with those made on this substance. But in the first place it is necessary to state that the apparatus used for forming, concentrating, and fixing the spectrum, was the same with that described in Art. 67. of that paper; the prism being that of flint-glass by Fraunhofer, there mentioned; the area of the section of the incident sunbeam = 1·54 square inch, and the dimensions of the principal elements of the luminous spectrum, identical with those recorded in §. 70, so that the following results, when numerically stated (in measures of which the unit is one-thirtieth of an inch), will be comparable with those previously described. To spare reference, however, it may be here mentioned that the diameter of the sun's image in the focus of the achromatic lens used is 7·20 of such thirtieths; and that the extent of the visible spectrum corrected for the sun's semidiameter at either end, equals 53·92 thirtieths, of which 13·30 are considered as reckoned negatively to the extreme visible red from a fiducial point or centre corresponding to the mean yellow ray; and 40·62 positively, from the same centre to the terminal violet, both as seen through a certain standard blue glass, which lets both extremes pass freely and insulates the mean yellow with considerable precision. The correction for the sun's semidiameter has been applied in what follows to all measures up to *terminations of spectra*, unless where the contrary is expressed. Maxima and minima of action, and neutral points neither require nor admit this correction.

Guaiacum.

151. A solution of this resin in alcohol, spread evenly on paper, gives a nearly colourless ground. A slip of this paper exposed to the spectrum is speedily impressed with a fine blue streak over the region of the violet rays, and far beyond, as described in Art. 92. If the paper during this action be carefully defended from extraneous light, this is the only perceptible effect; but if dispersed light be admitted, the general ground of the paper is turned to a pale brownish green, with exception of that portion on which the less refrangible rays fall, which, by their agency, is defended from the action of the dispersed light and preserves its whiteness, as in the case of the argentine paper described in Art. 60. The spectrum, therefore, ultimately impressed,

Fig. 1. Art. 151.

Fig. 2. Art. 153.

Fig. 3. Art. 155.

Fig. 4. Art. 176.

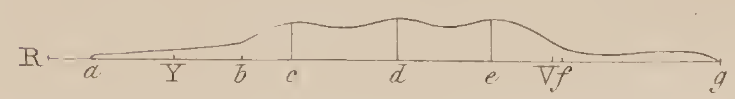


Fig. 5. Art. 176.

Fig. 6. Art. 188.

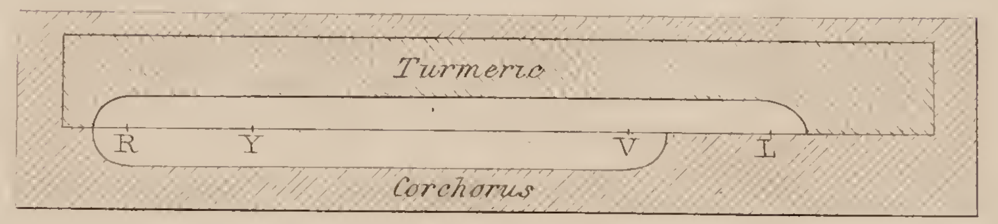


Fig. 7. Art. 191.

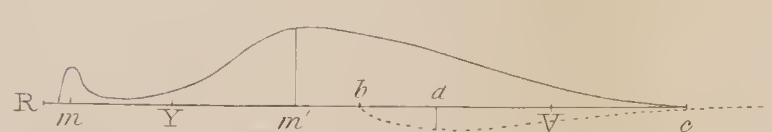
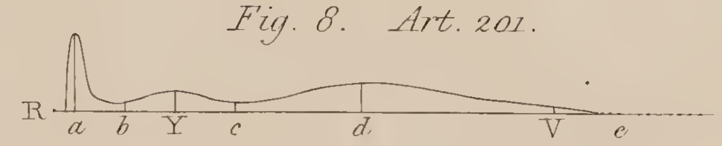


Fig. 8. Art. 201.



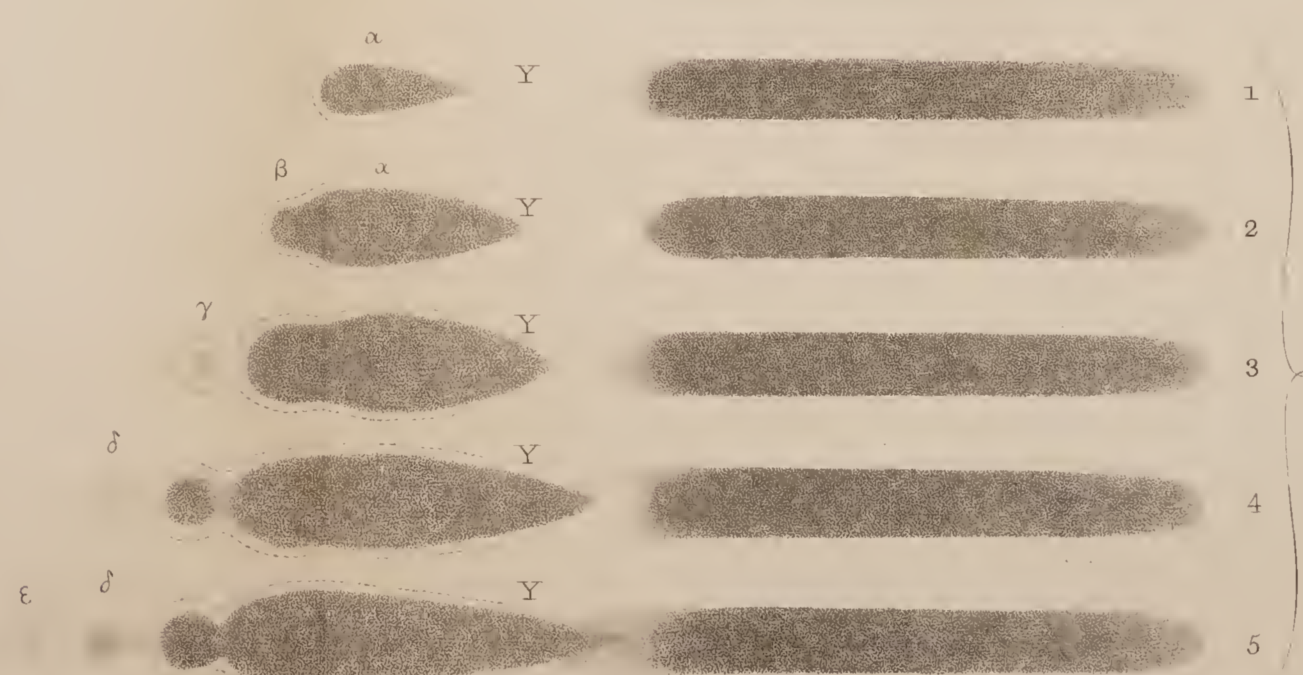


Fig. 9. Art. 206.

Thermographic Impressions. Photographic Impressions.

Fig. 12. Art. 214.

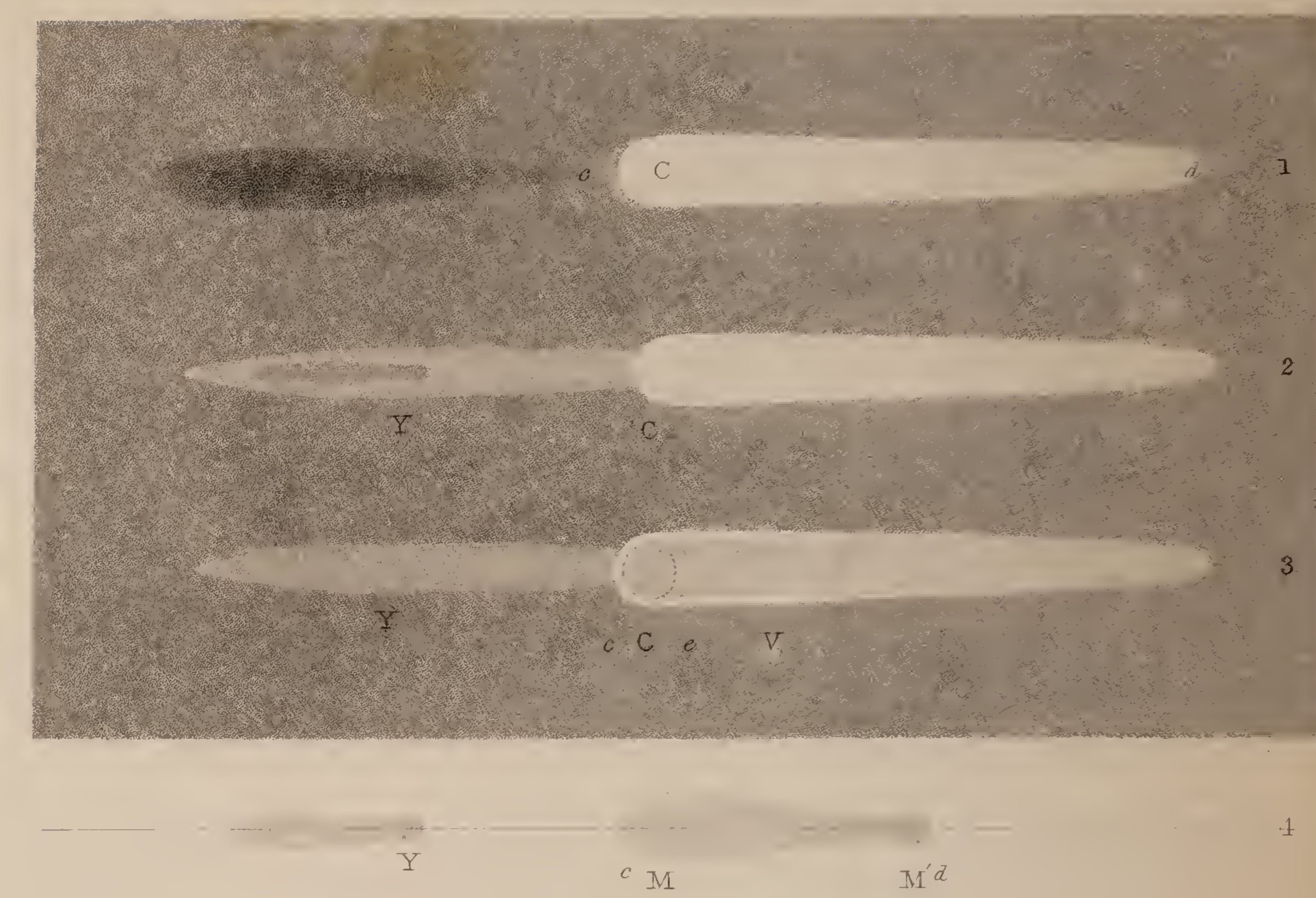
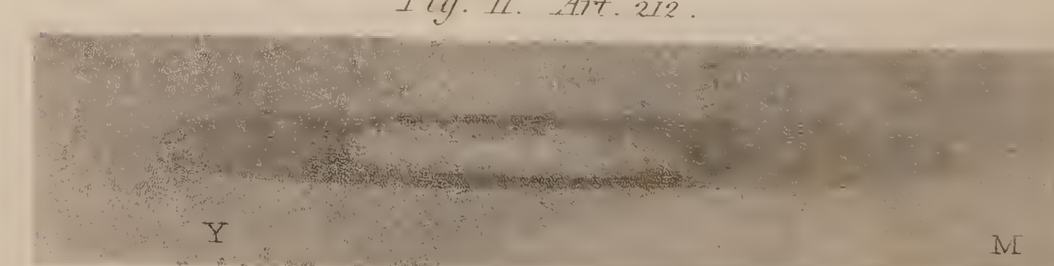


Fig. 10. Art. 207.

Fig. 11. Art. 212.



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consists of two portions similar to those described in Art. 93, and of nearly the same extent, that is to say, a white or pale yellowish portion having its maximum of intensity at 0·0, and extending from − 11·9 (corrected for the sun's semidiameter) to + 12·0, or thereabouts, at which point the character of the action changes, and a blue, of a somewhat smoky grey cast, commences, which attains a maximum at + 40·0, thence degrades to an intermediate minimum at + 47·0, attains a second and much stronger maximum at + 61·0, and ceases at 72·4. The precise numbers vary materially in different specimens and with the length of exposure. The type of this spectrum, of its natural length, is represented in Plate XV. fig. 1, in which the abscissæ being measured along the length of the spectrum, from the fiducial centre Y both ways, the ordinates express the intensities of photographic action at each corresponding point, as estimated from the amount of colour induced or prevented. In this type the portion corresponding to the less refrangible rays is represented by negative values of the ordinate agreeably to Art. 93, where it is shown that these rays not only prevent the blue colour from being produced by the more refrangible ones, but destroy it when so produced. Another specimen gave the following dimensions: Y a = − 11·4, Y b = − 9·5, Y c = + 30·0, Y d = + 61·0, Y e = + 80·4, and this is the greatest extent of action I have hitherto observed.

152. A portion of the same paper was exposed, dry, to an atmosphere of chlorine considerably diluted with common air, which imparted to it a pale, dirty, greenish yellow hue. Being thence transferred immediately to the spectrum, the result was not a little remarkable. The whole spectrum, the green excepted, was impressed in faint tints nearly corresponding to the natural ones. The red was evident—the yellow dilute and nearly white—the blue a fine sky-blue, while beyond the violet succeeded a train of somewhat greenish darkness. These tints proved fugitive, and in twenty-four hours were nearly obliterated.

153. When paper fresh washed with tincture of guaiacum and still wet is exposed to chlorine, it instantly acquires a fine and full Prussian blue colour, which however passes speedily to brown if the action be prolonged. The colour is difficult to preserve in its full intensity, and fades considerably in drying, becoming at the same time somewhat greenish. Exposed wet to the spectrum, it is found to have become much more sensitive, and is immediately attacked with great energy by the red rays, which destroy the blue colour, converting it to a brownish or reddish yellow. The action extends rapidly up the spectrum as far as the extreme violet, in which ray, however, the tint impressed or left undestroyed passes to a hue partaking of violet, and indicating by the change what ought probably to be regarded as a neutral point at + 12·0. The impressed spectrum (corrected for semidiameter) commences at a, fig. 2, at − 13·4; the maximum b of the positive action occurs at − 9·0, the neutral point c at + 12·0, the maximum d of negative action at + 33·0, and the sensible termination e of the impression at + 60·0.

154. The action of gaseous chlorine is too energetic to be easily arrested at the

proper point, besides which this gas also acts powerfully on the alcohol employed. To obviate these inconveniences, paper thoroughly impregnated with guaiacum by washing with the tincture, and drying in a gentle heat, was steeped in weak aqueous solution of chlorine, by which process it slowly acquired a beautiful and pure celestial blue colour. It is very sensitive, and may be conveniently used for copying engravings, &c., which it does with this singularity, that the picture penetrates the paper and appears on the back of very nearly the same intensity as on the face*. Indeed, if the picture be over sunned the back will exhibit a perfect impression, while the face is spoiled, which produces a very strange effect: exposed to the spectrum, the blue colour is converted to a pale reddish yellow in the region of the less refrangible rays, and simply whitened in the more refrangible region. The action, when prolonged till the light seems to have no further influence, extends from $-$ 12·4, corrected for semidiameter, to $+$ 40, or thereabouts, where it dies away insensibly. The maximum of photographic action occurs at $-$ 8·7, and some trace of a minimum is perceptible at $+$ 11·5. Photographs taken on this paper, or spectra impressed on it, are fugitive—lose much of their force and beauty in a few days, and at length vanish altogether.

155. When paper is washed with a solution of guaiacum in soda it acquires a green colour, though the solution itself is brown. By inclining the paper and carrying the wash always from below upwards, a very even tint may be obtained. The excess of liquid being blotted off, aqueous solution of chlorine was poured over it (on a slope) till all the alkali was saturated, and the liquid ran off smelling strongly of chlorine. Thus was produced a paper (No. 1168.) very evenly tinted, and varying in colour from a deep, somewhat greenish, to a fine celestial blue, according to the strength of the solutions employed. It is very sensitive, and is attacked with especial energy by rays in the spectrum, ranging from $-$ 11·4 to $+$ 11·4 with a maximum at $-$ 9·0, the type being as in fig. 3.

156. When paper so prepared is exposed, wet, to a temperature of 212° Fahr., it is immediately discoloured, the green changing to a sere or brownish yellow. The same change is produced after some little time at a temperature of 190°, and still more slowly, though yet completely, at 180°. At 175° the discoloration is incomplete and very slow; and below that temperature the colour is not affected. If the paper be perfectly dried in a temperature gradually raised to 212°, the discoloration requires a considerably higher temperature, ranging from 220° to 275°, according to the time of exposure, being very slow at the former limit and almost immediate at the latter. These changes are independent of the action of light, being produced under mercury.

157. The destruction by heat of the green or blue colour superinduced on guaiacum by the more refrangible rays of light, was noticed by Wollaston, and it would seem, on a consideration of his experiments and of those described in the last article, that nothing further is requisite for operating the change from the green or blue to

* For another remarkable case of this kind see the Postscript to this paper.

the yellow state, than the assumption of a certain temperature dependent on its state of dryness, and varying according to that state between the limits of 180° and 280°. Nevertheless, if we consider that the same change is produced by rays of the spectrum which are very far from being the *hottest,* while yet the extra-spectral thermic rays, under precisely the same circumstances of exposure, produce no such effect, though far surpassing in mere calorific power those which do, we shall see reason to doubt the sufficiency of this view of the matter. The following experiments were therefore instituted with a view to its further elucidation.

158. A slip of the paper No. 1168 was moistened and subjected in clear sunshine to the action of the spectrum. The colour was discharged from the region occupied by the less refrangible luminous rays, as described in Art. 155. At the same time, the more distant thermic rays beyond the spectrum produced their proper effect, in evaporating the moisture from those portions on which they fell; so that in due time the *heat-spots* δ and γ became apparent (see Art. 136), the former very distinctly, the latter perceptibly. The spot β (which is remarkable) was scarcely if at all formed. So long then as the paper continued moist and remained under the influence of the thermic rays, the appearances were those of *a diminution of colour* (Art. 131.), operated by the thermic rays δ and γ. But the discoloration in these points was only apparent, for as the paper dried these *heat-spots* disappeared, leaving its colour quite unchanged at those points; while the photographic impression really produced within the visible spectrum, remained and went on increasing in intensity. The non-luminous thermic rays, therefore, though clearly shown to have been active *as heat,* were yet incapable of effecting that peculiar chemical change which other rays much less copiously endowed with heating power, were all the while producing.

159. It may be objected to this, that no proof is afforded in the above-related experiment, that any part of the paper actually attained a temperature of 180° or more; that in consequence no discoloration due to the action of heat (*quoad heat*) was produced; and that the discoloration which did take place was *sui generis,* and originated with the *light and not the heat* of that part of the spectrum to which it corresponded. A slip of the same paper (1168.) was therefore exposed dry to the spectrum in such a way as to leave its back accessible; and an iron heated below redness was then approached to it so as *just not* to discolour the paper. Under such circumstances it might be expected that the additional heat thrown on the paper in the region of the thermic rays would turn the scale in their favour at their points of greatest intensity, and give ocular proof of their action by a decided discharge of colour at those points. But no such result was obtained, nor could I succeed in rendering visible any of the heat-spots α, β, γ, δ, even when the heated iron was brought so near as to produce a commencement of discoloration over the whole of that region of the paper where they ought to have shown themselves.

160. On the other hand, a remarkable, but by no means an unexpected, influence was exercised by the heat so thrown on that part of the paper where the less refran-

gible rays fell, and where the discoloration was in progress under their agency. For it was observed that, under these circumstances, the discoloration in question went on with much greater rapidity, so much so indeed, that the same amount of it, which without extraneous heat would have required twenty minutes or half an hour's exposure to the spectrum to produce, was now produced in two or three minutes. Obscure terrestrial heat, therefore, is shown to be capable of *assisting* and *being assisted* in operating this peculiar change, by those rays of the spectrum, whether luminous or thermic, which occupy its red, yellow, and green regions; while on the other hand it receives no such assistance from the purely thermic rays beyond the spectrum, acting under precisely similar circumstances, and in an equal state of condensation.

161. When heat was similarly applied by radiation from behind, and from a non-luminous source, over the *more* refrangible region of a spectrum thrown on paper simply washed with tincture of guaiacum and not previously blued either by chlorine or by light, the blue colour induced in the more refrangible rays was still produced, and of the same tint in the same points as if no heat had acted. This effect, the contrary to what the previous experiment would have led to expect, shows how little any reasonings on these points enable us at present to anticipate experience.

162. The discharge of colour from blued guaiacum by mere heat, has been shown above (Art. 156.) to take place at a much lower temperature in the presence of moisture than when dry; and a similar destruction of colour, under similar circumstances, takes place with many other vegetable preparations. Paper, for instance, coloured with the juice of the *Viola tricolor* (Art. 90.), is speedily whitened in the dark, while wet, by the heat of boiling water, though dry heat does not affect it. And under the action of the spectrum it is discoloured (though much more slowly) by the same, or nearly the same rays which are effective in the case of guaiacum. The colour of paper tinged with the juice of the common red stock is not affected when dry by any heat short of what suffices to scorch the paper, but when wet (as when exposed to steam) it is speedily discharged. There are few, if any vegetable colours indeed which long resist the combined effects of heat and moisture, even when light is excluded, still less when admitted*.

Of the Colours of Flowers in general under the action of the Spectrum.

163. In operating on the colours of flowers I have usually proceeded as follows:— the petals of the fresh flowers, or rather such parts of them as possessed a uniform tint, were crushed to a pulp in a marble mortar, either alone, or with addition of alcohol, and the juice expressed by squeezing the pulp in a clean linen or cotton cloth. It was then spread on paper with a flat brush, and dried in the air without artificial

* On the effects of light, air, and moisture at common temperatures, as discolouring agents on several dyeing materials, I may refer to M. Chevreul's elaborate memoir (Acad. R. des Sciences, tom. xvi.). M. Chevreul's experiments, however, relate to the action of light simply as it comes from the sun without prismatic separation, and have therefore little or nothing in common with the objects of this paper.

heat, or at most with the gentle warmth which rises in the ascending current of air from an Arnott stove. If alcohol be not added, the application on paper must be performed immediately, since exposure to the air of the juices of most flowers (in some cases even for but a few minutes) irrecoverably changes or destroys their colour. If alcohol be present this change does not usually take place, or is much retarded; for which reason, as well as on account of certain facilities afforded by its admixture in procuring an even tint (to be presently stated), this addition was commonly, but not always made.

164. Most flowers give out their colouring matter readily enough, either to alcohol or water. Some, however, as the Escholzias and Calceolarias, refuse to do so, and require the addition of alkalies, others of acids, &c. When alcohol is added, it should, however, be observed that the tint is often, apparently, much enfeebled, or even discharged altogether, and that the tincture, when spread on paper, does not reappear of its due intensity till after complete drying. The temporary destruction of the colour of the blue heartsease by alcohol has been noticed in my former paper (Art. 90.), nor is that by any means a singular instance. In some, but in very few cases, it is destroyed, so as neither to reappear on drying, nor to be capable of revival by any means tried. And in all cases long keeping deteriorates the colours and alters the qualities of the alcoholic tinctures themselves, so that they should always be used as fresh as possible.

165. If papers tinged with vegetable colours are intended to be preserved, they must be kept perfectly dry and in darkness. A close tin vessel, the air of which is dried by quicklime (carefully enclosed in double paper bags, well pasted at the edges to prevent the dust escaping), is useful for this purpose. Moisture (as already mentioned, especially assisted by heat) destroys them for the most part rapidly, though some (as the colour of the *Senecio splendens*) resist obstinately. Their destructibility by this agency, however, seems to bear no distinct relation to their photographic properties.

166. This is also the place to observe that the colour of a flower is by no means always, or usually, that which its expressed juice imparts to white paper. In many cases the tints so imparted have no resemblance to the original hue. Thus, to give only a few instances, the red damask rose of that intense variety of colour, commonly called by florists the Black Rose, gives a dark slate blue, as do also the clove carnation and the black holyoak; a fine dark brown variety of Sparaxis gave a dull olive green; and a beautiful rose-coloured tulip, a dirty bluish green; but perhaps the most striking case of this kind is that of a common sort of red poppy (*Papaver Rheum*?), whose expressed juice imparts to paper a rich and most beautiful blue colour, whose elegant properties as a photographic material will be further alluded to hereafter*.

* A semicultivated variety was used, having dark purple spots at the bases of the petals. The common red poppy of the chalk (*Papaver hybridum*) gives a purple colour much less sensitive and beautiful.

167. This change of colour is probably owing to different causes in different flowers. In some it undoubtedly arises from the escape of carbonic acid, but this as a general cause for the change from red to blue, has, I am aware, been controverted*. In some (as is the case with the yellow Ranunculi) it seems to arise from a chemical alteration depending on absorption of oxygen; and in others, especially where the expressed juice coagulates on standing, to a loss of vitality or disorganization of the molecules. The fresh petal of a single flower, merely crushed by rubbing on dry paper, and instantly dried, leaves a stain much more nearly approximating to the original hue. This, for example, is the only way in which the fine blue colour of the common field Veronica can be imparted to paper. Its expressed juice, however quickly prepared, when laid on with a brush, affords only a dirty neutral gray, and so of many others. But in this way no even tint can be had, which is a first requisite to the experiments now in question, as well as to their application to photography.

168. To secure this desirable evenness of tint, the following manipulation will generally be found successful. The paper should be moistened at the back by sponging and blotting off. It should then be pinned on a board, the moist side downwards, so that two of its edges (suppose the right-hand and lower ones) shall project a little beyond those of the board. The board being then inclined twenty or thirty degrees to the horizon, the alcoholic tincture (mixed with a very little water, if the petals themselves be not very juicy) is to be applied with a brush in strokes from left to right, taking care *not to* go over the edges which rest on the board, but *to* pass clearly over those which project, and observing also to carry the tint from below upwards by quick sweeping strokes, leaving no dry spaces between them, but keeping up a continuity of wet surface. When all is wet, cross them by another set of strokes from above downwards, so managing the brush as to leave no floating liquid on the paper. It must then be dried as quickly as possible over a stove, or in a current of warm air, avoiding, however, such heat as may injure the tint. The presence of alcohol prevents the solution of the gummy principle, which, when present, gives a smeary surface; but the evenness of tint given by this process results chiefly from that singular intestine movement which always takes place when alcohol is in the act of separation from water by evaporation—a movement which disperses knots and blots in the film of liquid with great energy, and spreads them over the surrounding surface.

169. The action of the spectrum, or of white light, on the colours of flowers and leaves, is extremely various, both as regards its total intensity and the distribution of the active rays over the spectrum. But certain peculiarities in this species of action obtain almost universally.

1st. The action is *positive*, that is to say, light destroys colour; either totally, or leaving a residual tint, on which it has no further, or a very much slower action. And thus is effected a sort of chromatic analysis, in which two distinct elements of

* Nicholson's Journal.

colour are separated, by destroying the one and leaving the other outstanding. The older the paper, or the tincture with which it is stained, the greater is the amount of this residual tint.

2nd. The action of the spectrum is confined, or nearly so, to the region of it occupied by the luminous rays, as contra-distinguished both from the so-called chemical rays, beyond the violet, which act with the chief energy on argentine compounds, but are here for the most part ineffective, on the one hand, and on the other, from the thermic rays beyond the red, which appear to be totally so. Indeed, I have hitherto observed no instance of the extension of this description of photographic action on vegetable colours beyond, or even *quite* up to the extreme red.

170. Besides these, it may also be observed that the rays effective in destroying a given tint, are, in a great many cases, those whose union produces a colour complementary to the tint destroyed, or at least one belonging to that class of colours to which such complementary tint may be referred. For example, yellows tending towards orange are destroyed with more energy by the blue rays; blues by the red, orange, and yellow rays; purples and pinks by yellow and green rays.

171. These are certainly remarkable and characteristic peculiarities, and must indeed be regarded as separating the luminous rays by a pretty broad line of chemical distinction from the non-luminous; though whether they act *as such*, or in virtue of some peculiar chemical quality of the heat which accompanies them *as heat*, is a point which the experiments on guaiacum, above described, seem to leave rather equivocal. In the latter alternative, chemists must henceforward recognize differences not simply of intensity, but of quality in heat from different sources; of quality, that is to say, not merely as regards degree of refrangibility or transcalescence, but as regards the strictly chemical changes it is capable of effecting in ingredients subjected to its influence.

172. As above stated, these peculiarities, at least the first two, obtain almost universally. Exceptions, however, though very rare, do occur, as will be more particularly mentioned hereafter. The third rule is much less general, and is to be interpreted with considerable latitude; but among its exceptions I have been unable to detect any common principle capable of being distinctly enunciated.

173. Lastly, it requires to be expressly mentioned, that the habitudes of the colours, both of the flowers and leaves of plants, with relation either to white light or to the prismatic rays, vary materially with the advance of the season, and perhaps also with the hour of the day at which they are gathered. Generally speaking, so far as I have been able to observe, the earlier flowers of any given species reared in the open air (provided they are well ripened, i. e. the colour fully developed) are more sensitive than those produced even from the same plant, at a late period in its flowering, and have their colours more completely discharged by light. As the end of the flowering period comes on, not only the destruction of the colour by light is slower, but residual tints are left which resist obstinately. A very remarkable case of this kind was no-

ticed in *Chryseïs californica*, the earliest flowers of which exhibited in the photograph of their spectrum a well-insulated round spot, eaten away by red rays almost at its extremity, which spot I never was able to reproduce with later flowers from the same root. Those gathered at the end of its flowering also left a residual yellow of extreme obstinacy*, which was by no means the case with the earlier flowers.

174. It would be waste of time to enumerate all the vegetable tints which I have subjected to experiment, comprising most of the ordinary hardy garden and wild flowers of the country. To the rarer and more splendid species which adorn the stoves and greenhouses of florists, I have had little access, a circumstance I much regret, and which leads me to take this opportunity of mentioning, that specimens of paper stained with the juices of highly-coloured, or otherwise remarkable flowers or leaves, either by alcoholic extraction, or by simple expression (if accompanied with the botanical name of the plant used), will be highly acceptable, from whatever quarter received. I shall here set down only those which afforded some ground for special remark, so far as I have yet pushed the inquiry.

Colours of particular Flowers.

175. *Corchorus Japonica.*—The flowers of this common and hardy but highly ornamental plant, are of a fine yellow, somewhat inclining to orange, and this is also the colour the expressed juice imparts to paper. As the flower begins to fade *the petals whiten*, an indication of their photographic sensibility, which is amply verified on exposure of the stained paper to sunshine. I have hitherto met with no vegetable colour so sensitive. If the flowers be gathered in the height of their season, paper so coloured (which is of a very even and beautiful yellow) begins to discolour in ten or twelve minutes in clear sunshine, and in half an hour is completely whitened. The colour seems to resist the first impression of the light, as if by some remains of vitality, which being overcome, the tint gives way at once, and the discoloration when commenced goes on rapidly. *It does not even cease in the dark when once begun.* Hence it happens that photographic impressions taken on such paper, which when fresh are very sharp and beautiful, fade by keeping, visibly from day to day, however carefully preserved from light. Specimens of such photographs (copies of engravings) are submitted with this paper for inspection. They require from half an hour to an hour to complete, according to the sunshine. Hydriodate of potash cautiously applied, retards considerably, but does not ultimately prevent, this spontaneous discharge.

176. Exposed to the spectrum, in about fifteen or twenty minutes the colour is totally destroyed and the paper whitened in the whole region of the green, blue and violet rays, to which therefore the most energetic action is confined, agreeably to the law of complementary tints (Art. 170.). If the action of the spectrum be prolonged,

* Probably, therefore, useful in dyeing. The species is that most commonly cultivated in gardens, with bright yellow petals having orange-coloured bases.

a much feebler whitening becomes sensible in the red, and a trace of it also beyond the violet into the "lavender" rays. In this state the type of the impressed spectrum (in an experiment made on the 7th of April in the present year) was as in fig. 4, indicating three obsolete maxima *c, d, e*, and a very sudden diminution of the action at *b, f*, the dimensions being as follows: $Y\,a = -9{\cdot}4$, $Y\,b = +7{\cdot}1$, $Y\,c = +12{\cdot}5$, $Y\,d = +23{\cdot}5$, $Y\,e = +34{\cdot}0$, $Y\!f = +41{\cdot}4$, $Y\,g = +59{\cdot}7$. The paper thus impressed was again re-examined on the 2nd of May, or after twenty-five days, during which interval it had been exposed to free air, but only to feeble and dispersed occasional lights. It was found to have undergone a remarkable change, two distinct white spots having become insulated, or nearly so, at the very extremities of the impressed spectrum, the three maxima above indicated having also become much more distinct, and two new, subordinate ones, having begun to show themselves in the faint traces connecting the spots above mentioned with the main impression. The type of the spectrum in this state was as represented in fig. 5, and the places of the several maxima being as follows:—1st, $-10{\cdot}0$; 2nd, $-0{\cdot}5$; 3rd, $+12{\cdot}0$; 4th, $+29{\cdot}0$; 5th, $+40{\cdot}0$; 6th, $+50$: :; 7th, $+61{\cdot}0$. The terminal spot at the red extremity was nearly equal in diameter to the sun's image; that at the least refracted end, corresponding in place to rays much beyond the last violet, was smaller, but perfectly distinct; and as it constitutes the only instance I have yet encountered of a *definite* ray in this region of the spectrum*, I have been thus particular in describing the phenomenon.

177. *Common ten-weeks Stock, Mathiola annua.*—The colour imparted by the petals of the *double variety* of this flower† to alcohol (at least when spread on paper, for it is in great measure dormant in the liquid tincture) is a rich and florid rose-red, varying, however, from a fiery tint almost amounting to scarlet, on the one hand, to a somewhat crimson or slightly purplish red on the other, according to the accidents of its preparation, or the paper used. When fresh prepared it is considerably sensitive, an hour or two of exposure to sunshine being sufficient to produce a sensible discoloration, and two or three days entirely to whiten it. This quality is greatly deteriorated by keeping, but papers prepared with it even after eight or ten months, still with patience yield extremely beautiful photographs, several specimens of which in various states of the tincture are submitted for inspection to the meeting. Exposed to the spectrum, the rays chiefly active in operating the discoloration are found to be those extending from the yellow to the less refrangible red, beyond which rays the action terminates abruptly. Above the yellow it degrades rapidly to a minimum in the blue, beyond which it recovers somewhat, and attains a second but much feebler maximum in the violet rays.

* Since this was written, other cases, extremely remarkable, among the argentine preparations, have presented themselves. See Art. 214.

† That imparted by the single flowers is very much less sensitive, as is also that of the dull red or purplish variety, whether double or single. The most florid red double flowers in the height of their flowering, yield the best colour.

178. Paper stained with the tincture of this flower is changed to a vivid scarlet by acids, and to green by alkalies; if ammonia be used the red colour is restored as the ammonia evaporates, proving the absence of any acid quality in the colouring matter sufficiently energetic to coerce the elastic force of the alkaline gas. Sulphurous acid whitens it, as do the alkaline sulphites; but this effect is transient, and the red colour is slowly restored by free exposure to air, especially with the aid of light, whose influence in this case is the more remarkable, being exactly the reverse of its ordinary action on this colouring principle, which it destroys irrecoverably, as above stated. The following experiments were made to trace and illustrate this curious change.

179. Two photographic copies of engravings taken on paper tinted with this colour were placed in a jar of sulphurous acid gas, by which they were completely whitened, and all traces of the pictures obliterated. They were then exposed to free air, the one in the dark, the other in sunshine. Both recovered, but the former much more slowly than the latter. The restoration of the picture exposed to sun was completed in twenty-four hours, that in the dark not till after a lapse of two or three days.

180. A slip of the stained paper was wetted with liquid sulphurous acid and laid on blotting-paper similarly wetted. Being then crossed with a strip of black paper, it was laid between glass plates and (evaporation of the acid being thus prevented) was exposed to full sunshine. After some time the red colour (in spite of the presence of the acid) was considerably restored in the portion exposed, while the whole of the portion covered by the black paper remained (of course) perfectly white.

181. Slips of paper, stained as above, were placed under a receiver, beside a small capsule of liquid sulphurous acid. When completely discoloured they were subjected (on various occasions, and after various lengths of exposure to the acid fumes from half an hour to many days) to the action of the spectrum; and it was found, as indeed I had expected, that *the restoration of colour was operated by rays complementary to those which destroy it in the natural state of the paper*; the violet rays being chiefly active, the blue almost equally so, the green little, and the yellow, orange, and most refrangible red not at all. In one experiment a pretty well-defined red solar image was developed by the *least* refrangible red rays also, being precisely those for which in the unprepared paper the discolouring action is abruptly cut off. But this spot I never succeeded in reproducing; and it ought also to be mentioned, that, according to differences in the preparation not obvious, the degree of sensibility, generally, of the bleached paper to the restorative action of light differed greatly; in some cases a perceptible reddening being produced in ten seconds, and a considerable streak in two minutes, while in others a very long time was required to produce any effect.

182. The dormancy of this colouring principle, under the influence of sulphurous acid, is well shown by dropping a little weak sulphuric acid on the paper bleached by that gas, which immediately restores the red colour in all its vigour. In like manner alkalies restore the colour, converting it at the same time into green.

183. *Papaver orientale.*—The chemical habitudes of the sulphurous acid render it highly probable that its action, in inducing a dormant state of the colorific principle, consists in a partial deoxidizement, unaccompanied however with disorganization of its molecules. And this view is corroborated by the similar action of alcohol already spoken of; similar, that is, in kind, though less complete in degree. Most commonly, vegetable colours, weakened by the action of alcohol, are speedily restored on the total evaporation of that ingredient. But one remarkable instance of absolute dormancy induced by that agent, has occurred to me in the case of the *Papaver orientale*, a flower of a vivid orange colour, bordering on scarlet, the colouring matter of which is not extractable otherwise than by alcohol, and then only in a state so completely masked, as to impart no more than a faint yellowish or pinkish hue to paper, which it retains when thoroughly dry, and apparently during any length of time without perceptible increase of tint. If at any time, however, a drop of weak acid be applied to paper prepared with this tincture, a vivid scarlet colour is immediately developed, thus demonstrating the continued though latent existence of the colouring principle. On observing this, it occurred to me to inquire whether, in its dormant state, that principle still retained its susceptibility of being acted on by light, since the same powerful and delicate agent which had been shown, in so many cases as to constitute a general law, capable of disorganising and destroying vegetable colours actually developed, might easily be presumed competent to destroy the capacity for assuming colour, in such organic matter as might possess it, under the influence of their otherwise appropriate chemical stimuli. A strip of the paper was therefore exposed for an hour or two to the spectrum, but without any sensible effect, the whole surface being equally reddened by an acid. As this experiment sufficiently indicated the action of light, if any, to be very slow, I next placed a strip, partly covered, in a south-east window, where it remained from June 19 to August 19, receiving the few and scanty sunbeams which that interval of the deplorable summer of 1841 afforded. When removed, the part exposed could barely be distinguished from the part shaded, as a trifle yellower. But on applying acid, the exposed and shaded portions were at once distinguished by the assumption of a vivid red in the latter, the former remaining unchanged.

184. A mezzotinto picture was now pressed on a glazed frame over another portion of the same paper, and abandoned on the upper shelf of a green-house to whatever sun might occur from August 19 to October 19. The interval proved one of almost uninterrupted storm, rain, and darkness. On removal, no appearance whatever of any impressed picture could be discerned, nor was it even possible to tell the top of the picture from the bottom. It was then exposed in a glass jar to the fumes of muriatic acid, when, after a few minutes, the development of the dormant picture commenced, and slowly proceeded, disclosing the details in a soft and pleasing style. Being then laid by in a drawer, with free access of air, the picture again faded, by very slow degrees, and on January 2, 1842, was found quite obliterated. Being then

again subjected to the acid vapour, the colour was reproduced. How often this alternation might have gone on I cannot say, the specimen having been mislaid or destroyed. But a portion of such paper photographically impressed with a stamped pattern, accompanies this communication for the satisfaction of any Member who may wish to try the experiment. The extreme slowness of the action precludes any prismatic analysis of the process, and it cannot be too often repeated *that the use of coloured glasses in such inquiries serves only to mislead.* Of dormant photographic impressions generally, whether slowly developing themselves by lapse of time, or at once revivable by stimuli, as well as of the spontaneous fading and disappearance of such impressions, I shall have more to say hereafter, having encountered several very curious cases of the kind in studying the habitudes of gold, platina, &c. I would here only observe, that a consideration of many such phenomena has led me to regard it as not impossible that the retina itself may be *photographically* impressible by strong lights, and that some at least of the phenomena of visual spectra and secondary colours may arise from the sensorial perception of actual changes in progress in the physical state of that organ itself, subsequent to the cessation of the direct stimulant.

TURMERIC.—*Further proofs of the continuation of the visible Prismatic Spectrum beyond the extreme Violet.*

185. The action of light on paper coloured with the alcoholic tincture of turmeric is but feeble. If long continued, however, it is whitened in the region of the blue and violet rays, from + 10 to + 43, or thereabouts, the maximum being at + 23·5. The paper browned by carbonate of soda is somewhat more sensitive, especially when wet, in which case an abruptly terminated action is perceptible in the red region, giving rise to a double maximum at − 10·0 and + 22·5, with an intermediate minimum at − 4·0. I should not have thought it necessary, however, to mention this paper, but on account of a remarkable peculiarity in its reflective power, in virtue of which it renders very plainly visible a prolongation of the spectrum beyond the extreme violet, in the region of what I have termed in my last paper, the Lavender rays. As the experiment is easily made, and affords a ready method of rendering visible this part of the spectrum, I shall describe, with some minuteness, the appearances which presented themselves in my experiments, and which seem to place the real existence of those heretofore undescribed luminous rays beyond all reasonable objection, should any doubt have arisen as to the interpretation of the phenomenon described in my former paper (Art. 59.).

186. Paper stained with tincture of turmeric is of a brilliant yellow colour, and in consequence, the spectrum thrown on it, if exposed in the open daylight, is considerably affected in its apparent colours, the blue portion appearing violet, and the violet very pale and faint; but beyond the region occupied by the violet rays is distinctly to be seen a faint prolongation of the spectrum, terminated laterally, like the rest of it, by strait and sharp outlines, and which in this case affects the eye with the sensation of

a pale yellow colour. Comparative measures were carefully taken of the spectrum so prolonged, and of the ordinary spectrum as seen projected on white paper, the results being as follows (see fig. 6.):—

	Parts.
Length of the spectrum Y L from the fiducial point Y to the visible termination L, as seen (with the naked eye) on the turmeric paper; corrected for ⊙'s semidiameter.	= 56·6
Length Y V from the same fiducial point to the visible termination, as similarly seen when projected on white paper	= 40·4
Prolongation rendered visible by projection of the spectrum on turmeric paper	= 16·2

187. The day on which this experiment was first made (May 27, 1841) was serene and clear, but being aware that in certain states of the atmosphere a vertical beam of halo-light passes through the sun, which in a meridional position of that luminary *might* give rise to a perceptible prolongation, both upwards and downwards (though in fact no such prolongation was perceived at the red end), it was often repeated, and always with the same result, on subsequent occasions, whether the sun were on or near the meridian, or otherwise. Comparative trials, also with other yellow papers, fully satisfied me of the cause being traceable to a peculiarity in the colouring material, as to its reflective powers. In particular, a certain paper (No. 1055.) coloured with the juice of *Chryseïs californica*, whose tint was almost identical with that of the turmeric paper, only somewhat *brighter*, was tried, and the spectrum measured on this paper was found to terminate precisely at 44·0, i. e. (correcting for semidiameter) at 40·4, the very same as if white paper had been used.

188. To test the matter yet more pointedly, a strip of turmeric paper was fixed on the *Chryseïs* paper, so that its edge should bisect the spectrum longitudinally from end to end, the preceding half of the sun's lengthened image being received on the one paper, and the following half on the other. The papers thus arranged were so similar as hardly to be distinguished when simply laid in sunshine, but when illuminated by the spectrum, as above described, the half of it on the turmeric side was plainly seen to extend far beyond the other, as represented in fig. 6.

189. Hitherto I have met with only one other coloured paper which possesses a similar character in respect of its reflective power, and that by no means in so high a degree. To prepare it, the alcoholic tincture of the dark purple dahlia must be alkalized by carbonate of soda. The mixture is vivid green, which is also, at first, the colour of paper stained with it. But this colour changes in about twenty-four hours to a fine yellow, a little inclining to orange, after which it is remarkably permanent, and very little sensible to photographic impression. On this, as on the turmeric paper, the prolongation of the spectrum appears as a pale yellow streak. And if such, rather than lavender or dove-colour, should be the true colorific character of these rays, we might almost be led to believe (from the evident reappearance of redness mingled with

blue in the violet rays) in a repetition of the primary tints in their order, beyond the Newtonian spectrum, and that if by any concentration rays still further advanced in the "chemical" spectrum could be made to affect the eye with a sense of light and colour, that colour would be green, blue, &c., according to the augmented refrangibility.

190. *Cases of negative Photographic Action on Vegetable Tints.*—Among a collection of plants which I made at the Cape of Good Hope, and have succeeded in rearing in England, occurred three species of a genus allied to Anthericum, with brilliant yellow flowers in lengthened spikes, and highly characteristic furred anthers, to which I am not botanist enough to assert the correct application of the name Bulbine, assigned to them by a friend in Cape Town. Of these three species, two (*Bulbine bisulcata* and . . . . .) yield from the green epidermis of their leaves and flower-stalks a bright yellow juice, which darkens rapidly on exposure to light, changing at the same time to a ruddy brown. Exposed to the spectrum, the less refrangible rays are found inoperative, either in inducing the change of tint, or in preserving that portion of the paper on which they fall from the influence of dispersed light. The negative action commences at the fiducial yellow, is very feeble as far as + 10, where it begins to increase, and is strong at + 23, where the maximum of effect is situated. Hence it degrades more slowly, is still pretty strong at + 60, and may be traced as far as 80, being therefore nearly commensurate with the spectrum impressed on nitro-argentine paper, a range of action unique, so far as my experience goes in vegetable photography. The species experimented on is that which (supposing it undescribed) I should be disposed to call *triangularis*, from the angular section of its long, slender, smooth, solid leaves; which, with the singular character of its juice, may serve to identify the species, my own specimen (a single one) having been destroyed by insects after flowering superbly. The ultimate tint acquired by the juice is a deep brown, to which it also passes in darkness, but much more slowly. The juices of both species, however, have the same photographic characters.

191. *Cheiranthus cheiri, Wall-flower.*—A cultivated double variety of this flower, remarkable for the purity of its bright yellow tint, and the abundance and duration of its flowers, yields a juice when expressed with alcohol, from which subsides, on standing, a bright yellow, uniform, finely divided fecula, leaving a greenish yellow transparent liquid, only slightly coloured, supernatant. The fecula spreads well on paper, and is very sensitive to the action of light, but appears at the same time to undergo a sort of chromatic analysis, and to comport itself as if composed of two very distinct colouring principles, very differently affected. The one on which the intensity and sub-orange tint of the colour depends is speedily destroyed, but the paper is not thereby fully whitened. A paler yellow remains as a residual tint, and this, on continued exposure to light, so far from diminishing in tone, slowly darkens to brown. Exposed to the spectrum, the paper is first speedily reduced nearly to whiteness in the region of the blue and violet rays. More slowly, an insu-

lated solar image is whitened at $-10{\cdot}5$, or in the less refrangible portion of the red, and the impresssd spectrum assumes the type represented in fig. 7, where $m\,\mathrm{Y} = -10{\cdot}5$; $m'\,\mathrm{Y} = +13{\cdot}0$; $\mathrm{Y}\,c = +55$. The exposure continuing, a brown impression begins to be perceived in the midst of the white streak, which darkens very slowly from $+18{\cdot}6$ to $+42$. It never attains any great intensity, but presents a singular appearance in the midst of the white train previously eaten out.

192. The juice in question contains gallic acid, and probably tannin, as is evident from its striking a strong black with persalts of iron. The gallic acid itself (whose singular properties, in conjunction with nitrate of silver, have been developed by Mr. TALBOT, as the basis of his all but magical process of the calotype*) is affected also negatively by light. Paper washed with its spirituous solution and partially covered, being exposed several months in a window, was found pretty strongly darkened in all the exposed portion. The action is too slow for prismatic analysis, and I am far from attributing to the presence of this acid the phenomenon above recorded. It would rather appear as if some portion of a more decidedly negative ingredient analogous to that which exists in the *Bulbine*, were present. As regards the positive ingredient, I may mention here the common Marigold (in which also the colour resides in an insoluble fæcula) as a flower in which the colouring principle is probably identical both with this and with that of the *Corchorus Japonica*, since it comports itself in the very same manner under the spectrum,—is nearly, or quite as sensitive, and is moreover fugitive, even when carefully defended from light, giving photographs which cannot be preserved. Many other flowers also contain in their juices a portion of this identical, or a very similar yellow principle, probably in a state of greater solubility, and thence disposed to the absorption of oxygen. Thus the juice of a fine purely yellow species of *Mimulus*†, if expressed, with or without alcohol, though vividly yellow in the first moments of expression, passes almost instantly to dirty green, and loses its sensibility to light; but if crushed on paper and immediately dried, the petals give a bright yellow stain which agrees in sensibility, and in the type of the impressed spectrum with the *Corchorus*. The *Ferranea undulata*, a dark brown flower, yields, when expressed, a dull green juice, which, spread on paper and dried, turns very speedily blue under the influence of the blue and violet rays of the spectrum; owing to the destruction of this yellow principle, which, mingling with the the substratum of blue (itself a much more indestructible tint), gives it its natural tinge of green. A similar destruction, of probably again the same yellow matter, in

* Preparations of the gallic acid in conjunction with silver, are noticed by me in my former paper as forming a "problematic exception" to my general want of success in procuring at the very outset of my photographic experiments (in February 1839), papers more sensitive than the simple nitrated or carbonated ones. The problematic feature consisted in spontaneous darkening of the papers laid by to dry in the dark, so at least then considered, but really arising doubtless from light incident on them in their preparation. Acetate of silver was used in their preparation.

† *Mimulus Smithii* (Lindl.).

the colour of the American Marigold*, causes its tint to pass rapidly in sunshine from brown to green, after which continued exposure produces no further change. The yellow colour of fresh bees'-wax and of palm-oil, are also, I doubt not, referable to the same, or a nearly similar colouring matter, both being very speedily bleached by exposure to light.

193. *Viola odorata.*—Chemists are familiar with the colour of this flower as a test of acids and alkalies, for which, however, it seems by no means better adapted than many others; less so, indeed, than that of the *Viola tricolor*, the common purple Iris, and many others which might be named. It offers, in fact, another, and rather a striking instance of the simultaneous existence of two colouring ingredients in the same flower, comporting themselves differently, not only in regard to light but to chemical agents. Extracted with alcohol, the juice of the violet is of a rich blue colour, which it imparts in high perfection to paper. Exposed to sunshine, a portion of this colour gives way pretty readily, but a residual blue, rather inclining to greenish, resists obstinately, and requires a very much longer exposure (for whole weeks indeed) for its destruction, which is not even then complete. Photographic impressions, therefore, taken on this paper, though very pretty, are exceedingly tedious in their preparation, if we would have the lights sharply made out.

194. The residual tint thus outstanding, after long exposure, is turned, not green, but yellow, by alkalies; or, if greenish at first, a very few hours suffice for the destruction of the slight remnant of blue, and the consequent appearance of the yellow colour. Reasoning on this fact, as well as on the action of light above mentioned, it seems highly probable that the tincture in question holds in solution two distinct colouring principles, of which the one (greatly preponderant in quantity) is destructible by light, and either destroyed or turned green by alkalies; the other, indestructible by light, and either naturally yellow in colour or changeable into yellow by alkaline agency.

195. This view of the composite nature of the colour in question receives corroboration from the habitudes of the alcoholic tincture above mentioned, when rendered green by admixture of carbonate of soda. On making this addition it becomes evident that a large amount of colour has been destroyed; the green tint imparted by it to paper being far less intense than might be expected from the intensity of the original hue, and from the trifling dilution caused by the small quantity of alkaline liquid required to effect the change. What remains is a fine green; but when exposed to light, the blue constituent alone of that green is destroyed, and a residual tint of pure yellow, which is very indestructible by light, is left. Exposure of a slip of such paper to the spectrum proves this change to be operated almost wholly by rays less refrangible than the fiducial yellow. A slight discoloration is perceived in the indigo-blue rays (at about $+30$), but the *green* appears quite inactive.

196. In the case of the purple Iris mentioned above, when turned green by the

* French Marigold, *Tagetes Patula*.

same reagent, the tint is fuller and richer, as well as, photographically, more sensitive, and the residual yellow less abundant. And in this case the resistance of the tint to rays of its own colour is very strongly marked. The spectral impression consists, in fact, of two portions clearly separated by the whole of the interval occupied by the green and greenish blue rays, conformably to the general remark in Art. 170.

197. *Sparaxis tricolor ?, var.—Stimulating effect of alkalies.*—Among a great many hybrid varieties of this genus, lately forwarded to me from the Cape, occurred one of a very intense purplish brown colour, nearly black. The alcoholic extract of this flower in its liquid state is rich crimson brown. Spread on paper it imparted a dark olive green colour, which proved perfectly insensible to very prolonged action, either of sunshine or the spectrum. The addition of carbonate of soda changed the colour of this tincture to a good green, slightly inclining to olive, and which imparted the same tint to paper. In this state, to my surprise, it manifested rather a high degree of photographic sensibility, and gave very pretty pictures with a day or two of exposure to sunshine. When prepared with the fresh juice there is hardly any residual tint, but if the paper be kept, a great amount of indestructible yellow remains outstanding. The action is confined chiefly to the negative end of the spectrum, the maximum being at $-$ 8·0, and the sensible limits of the impression (corrected for semidiameter) being $-$ 11·0 and $+$ 56·4, of which, however, all but the first five or six parts beyond the fiducial yellow show little more than a trace of action. A photograph impressed on this paper is reddened by muriatic acid fumes. If then transferred to an atmosphere of ammonia, and when supersaturated the excess of alkali allowed to exhale, it is fixed, and of a dark green colour. Both the tint and sharpness of the picture, however, suffer in this process.

198. *Red Poppy—Papaver Rheum ?.*—Among the vegetable colours totally destroyed by light, or which leave no residual tint, at least when fresh prepared, perhaps the two most rich and beautiful are those of the red poppy, and the double purple groundsel (*Senecio splendens*). The former owes its red colour in all probability to free carbonic acid, or some other (as the acetic) completely expelled by drying, for the colour its tincture imparts to paper, instead of red is a fine blue, very slightly verging on slate-blue. But it has by no means the ordinary chemical characters of blue vegetable colours. Carbonate of soda, for instance, does not in the least degree turn the expressed juice green; and when washed with the mixture, a paper results of a light slate-gray, hardly at all inclining to green. The blue tincture is considerably sensitive, and from the richness of its tone and the absence of residual tint, paper stained with it affords photographic impressions of great beauty and sharpness, some of which will be found among the collection submitted with this paper for inspection.

199. *Senecio splendens.*—This flower yields a rich purple juice in great abundance and of surprising intensity. Nothing can exceed the rich and velvety tint of

paper tinted with it while fresh. It is, however, exceedingly insensible to light, and it is only by an exposure continued for many weeks, that it is possible to get a complete photographic impression of a picture on it. Still, when obtained, owing to the whiteness of the ground, the effect is pleasing, and would be beautiful were it not that the general tint suffers somewhat in its tone and softness of surface.

200. The juices of the leaves, stalks, roots, &c. of plants afford a wide and interesting field of photographic inquiry. Those of leaves are for the most part green, and being usually loaded with gum, extractive, &c., are difficult of manipulation. Such as I have tried, which spread well on paper, as the elder, the potatoe, the nightshade, and a few others, proved very sensitive if gathered when just in the perfection of their development, and in full vitality. As the season advances they lose much of their sensibility. There is much uniformity in the action of the spectrum on their colour, in consequence of which I shall content myself with describing the phenomena as exhibited on that of the elder leaf. The type of the impressed spectrum in this case is, as in fig. 8, exhibiting a strong decided maximum of action, giving rise to a nearly insulated solar image at $-$ 11·5, or almost at the extremity of the red rays. The colour of this image was a pale yellowish pink or flesh colour ; from thence the action is feeble, with two subordinate minima (at $-$ 5·0, $+$ 6·8), with a slight intermediate maximum at 0·0, and beyond these (or about the termination of the green) the action again increases ; reaches another maximum at $+$ 20·0, after which it declines gradually, and beyond $+$ 45 ceases to be traceable. Photographic pictures may be taken readily on such papers, half an hour in good sun sufficing ; but the glairy nature of the juices prevents their being evenly tinted, and spoils their beauty*.

201. The ruddy tint which comes out when the green is destroyed by light, is in all probability that which gives the whole colour to sere and withered leaves, whether simply disclosed by the destruction of the green which masked it in the live state of the leaf, or matured by exposure to light during the whole season, either out of the elements of the green colouring matter destroyed, or from the other juices of the vegetable. It deserves to be noticed in connexion with this, that all the lively vegetable greens have a large portion of red in their composition, and are in fact dichromatic. A good example of such a colour is a solution of sap-green, which, used as a prism, is seen to transmit both red and green rays, separating them by a broad interval which increases as the thickness or density of the solution is increased ; the red ultimately preponderating, and the green being extinguished. If we view a garden or shrubbery through a glass of a pure and deep red colour, every shrub, such as the laurel, of a lively and brilliant foliage, and especially green grass, will appear scarlet. Under such circumstances, a grass-plot, seen in contrast with a gravelled walk, shows as light on darkness, contrary to their habitual order of illumination. So great is the quantity of extreme red light reflected by a green sward, as actually

* I have not operated on chlorophyle (the green colouring matter of leaves) in a state of purity, owing to the nicety required in its preparation.

to appear bright in opposition to clear blue sky seen through the same glass in the quarter of the heavens opposed to the sun, and that at noon day. The aspect of nature, indeed, when viewed through coloured glasses, is fraught with curious and interesting matter of optical remark; but to give them their full effect they must not be merely applied to one eye for a few moments, as in the use of Claude Lorraine glasses. They should be worn as spectacles, both eyes being used, all lateral light carefully excluded by black velvet fringes, and their use continued till the pupil is fully dilated and the eye familiarized with the intensity and tone of the illumination. So used, not only are the ordinary relations of all lights and colours strangely and amusingly deranged, but contrasts arise between colours naturally the most resembling, and resemblances between those naturally the most opposed. We become aware of elements in the composition of tints we should otherwise never have suspected, and the singularities of idio-chromic vision which seem so puzzling, when related, cease to be matter of any surprise*.

202. I shall conclude this part of my subject by remarking on the great number and variety of substances which, now that attention is drawn to the subject, appear to be photographically impressible. It is no longer an insulated and anomalous affection of certain salts of silver and gold, but one which, doubtless, in a greater or less degree pervades all nature, and connects itself intimately with the mechanism by which chemical combination and decomposition is operated. The general instability of organic combinations might lead us to expect the occurrence of numerous and remarkable cases of this affection among bodies of that class, but among metallic and other elements inorganically arranged, instances enough have already appeared, and more are daily presenting themselves, to justify its extension to all cases in which chemical elements may be supposed combined with a certain degree of laxity, and so to speak, in a state of tottering equilibrium. There can be no doubt that the process, in a great majority if not all the cases which have been noticed among inorganic substances, is a deoxidizing one, so far as the more refrangible rays are concerned. It is obviously so in the cases of gold and silver. In that of the bichromate of potash it is most probable that an atom of oxygen is parted with, and so of many others. A beautiful example of such deoxidizing action on a non-argentine compound has lately occurred to me in the examination of that interesting salt, the ferrosesquicyanuret of potassium, described by Mr. Smee in the Philosophical Magazine, No. 109, September 1840, and which he has shown how to manufacture in abundance and purity by voltaic action on the common, or yellow ferrocyanuret. In this process nascent oxygen is absorbed, hydrogen given off, and the characters of the result-

* The late celebrated optician Mr. Troughton, who was a remarkable instance of this sort of vision, informed me that he could not distinguish the scarlet coats of a regiment of soldiers from the green turf on which they were drawn up, nor ripe cherries from the leaves of the tree which bore them. His eyes, however, were perfectly sensible to rays of every refrangibility *as light*, but the spectrum afforded him only the sensations of two *colours*, which he termed blue and yellow; pure red and pure yellow rays exciting in his mind the same sensation.

ing compound in respect of the oxides of iron, forming as it does Prussian blue with protosalts of that metal, but producing no precipitate with its persalts, indicate an excess of electro-negative energy, a disposition to part with oxygen, or, which is the same thing, to absorb hydrogen (in the presence of moisture), and thereby to return to its pristine state, under circumstances of moderate solicitation, such as the affinity of protoxide of iron (for instance) for an additional dose of oxygen, &c.

203. Paper simply washed with a solution of this salt is highly sensitive to the action of light. Prussian blue is deposited (the base being necessarily supplied by the destruction of one portion of the acid, and the acid by the decomposition of another). After half an hour or an hour's exposure to sunshine, a very beautiful negative photograph is the result, to fix which all that is necessary is to soak it in water, in which a little sulphate of soda is dissolved, to ensure the fixity of the Prussian blue deposited. While dry, the impression is dove-colour or lavender blue, which has a curious and striking effect on the greenish yellow ground of the paper produced by the saline solution. After washing, the ground colour disappears, and the photograph becomes bright blue on a white ground. If too long exposed it gets "oversunned," and the tint has a brownish or yellowish tendency, which however is removed in fixing: but no increase of intensity beyond a certain point is obtained by continuance of exposure.

204. Prismatic examination of this process demonstrates the remarkable and valuable fact, that the decomposition of the salt and deposit of Prussian blue is due to the action of the blue and violet rays, the less refrangible rays below the blue having absolutely no influence either to exalt or diminish the effect. The limits of action are about + 18·0 and + 61·0, fading insensibly both ways. The greatest intensity of action is at + 38. A feebler maximum occurs at + 23. The intensity of the impression is much increased by washing with acidulated water, still more if it hold in solution a little persalt of iron, but in this case the ground, if not very carefully defended from light, is blue.

205. If a solution of this salt, mixed with perchloride of iron in a certain proportion, be washed over paper somewhat bibulous and exposed to the spectrum, a copious and intense deposit of Prussian blue takes place over the region indicated in the last article. But it does not terminate there. On the contrary, the action is continued downwards in the spectrum, not only down to and beyond the extreme red rays, but far below, *down to the very end of the thermic spectrum* (as far as the spot called δ in Art. 136, and even with some traces of the more remote spot ε). The formation of the deposited colour in this region is accompanied with very singular phenomena, referable obviously to the heat developed by the thermic spectrum. Soon after the blue train, *a b*, fig. 9, in the positive region of the spectrum is formed, and has begun to acquire some intensity, an oval α, blunt at one extremity and pointed at the other, and of a dark brown colour, begins to appear. It enlarges rapidly, and at the same time throws forth a projection β, indicating the action of that portion of the

thermic spectrum so characterized in Art. 136. It also acquires a whitish narrow border, indicated by the dotted line, and very conspicuous on the green ground of the paper. The action continuing, the spot γ is marked out by the extension of the border in that direction, soon after which the spot appears, in brown. Lastly appears δ with feeble traces of further irregular and interrupted action. Measurements of these spots as they appear, leave no doubt of their identity in situation with the thermic spots α, β, γ, δ of Art. 136, and that they are referable to the drying of the paper is shown by the fact, that a film of the liquid dried in a porcelain saucer changes from green to dark brown at a definite point of dryness. Moreover, on wetting the paper, the brown spots disappear, and in their place we find a train of Prussian blue, of varying intensity, but *of uniform breadth* (not swelling and contracting, as is the case with the heat-spots formed by simple drying, and *therefore* obviously due to *direct* radiation), and terminating in two insulated and tolerably well-defined circular spots or solar images, holding precisely the places of γ and δ (viz. at $-35{\cdot}7$ and $-45{\cdot}1$).

206. If in lieu of the perchloride of iron, we substitute a solution of that curious salt the *ammonio-citrate of iron*, the photographic effects are among the most various and remarkable that have yet offered themselves to our notice in this novel and fertile field of inquiry. The two solutions mix without causing any precipitate, and produce a liquid of a brown colour, which washed over paper is green (being strongly dichromatic). If this be done under the prism, the action of the spectrum is almost instantaneous, and most intense. A copious and richly coloured deposit of Prussian blue is formed over the whole of the blue, violet, and extra-spectral rays in that direction, extending downwards (with rapid graduation) almost to the yellow. If arrested when the blue is most intense and thrown into water, the impression is fixed, as in the accompanying specimen (see fig. 10.). But if the action of the light be continued, strange to say, the blue and violet rays begin to destroy their own work. A *white* oval makes its appearance in the most intense part of the blue (fig. 11.), which extends rapidly upwards and downwards. At a certain point of the action, the upper or more refrangible extremity of the white impression exhibits a semicircular termination, beyond which is a distinct and tolerably well-defined *conjugate image*, or insulated circular white spot, whose centre is situated far beyond the extreme visible violet.

207. If paper washed over with the mixed solution in question is exposed wet to sunshine, it darkens to a livid purple and rapidly whitens again. If the exposure be continued, the white again darkens gradually to a brownish violet hue. But in the shade it slowly resumes its original tint, after which it is again and again susceptible of the same round of action. The most singular and apparently capricious varieties of coloration and discoloration however arise (as is so frequently the case in photographic experiments) from different dosage of ingredients, order of washes, &c., so as to make the study of the phenomena in a high degree complicated*. A certain adjustment

* The whitening is very obviously due to the deoxidation of the precipitated Prussian blue and the formation

of proportions gives an exquisite and highly sensitive *positive* photographic paper; another, a negative one, in which the impression of light, feeble at first, is strongly brought out afterwards by an additional wash of the ferrosesquicyanuret, &c.

208. The ordinary ferrocyanuret (the yellow salt), though not nearly so sensible to photographic action, is yet far from inert. In my former paper I have noticed its property of fixing against the further action of light, and ultimately destroying, photographic impressions on argentine papers. In conjunction also with preparations of silver, it has been made by Mr. HUNT the basis of a highly sensitive photographic paper. Its habitudes *per se* are, however, not a little remarkable. Paper simply washed with its fresh solution and exposed to the spectrum, slowly receives a deposit of Prussian blue over the region of the blue, violet, and "lavender" rays: but this never becomes intense; another series of changes commencing, indicated by the formation of a violet-coloured streak within the blue, just where the violet itself is most intense in the spectrum. If the solution be very feebly acidulated with sulphuric acid, the first portion only of the spectral impression (from + 13·3 to + 20·0) is blue, the whole of the remainder (extending to + 51) snuff brown. The dose of acid being increased, the exposure prolonged, and the liquid plentifully supplied, a green thermic impression is produced by the less refrangible rays, in which the spots α, β, γ are very distinct, and lie exactly (by measure) in their proper places. This impression continues as far as the zero point, where it begins to pass into blue, and graduates insensibly into the photographic spectrum, which attains its maximum of blue at + 25, and is thence prolonged onwards as a dull bluish streak on a brown ground, somewhat broader than itself, and projecting like a border on both sides.

209. If paper be washed with a solution of ammonio-citrate of iron and dried, and then a wash passed over it of the yellow ferrocyanuret of potassium, there is no immediate formation of true Prussian blue, but the paper rapidly acquires a violet purple colour, which deepens after a few minutes, as it dries, to almost absolute blackness. In this state it is a positive photographic paper of high sensibility, and gives pictures of great depth and sharpness, but with this peculiarity, that they darken again spontaneously on exposure to air in darkness, and are soon obliterated. The paper, however, remains susceptible to light and capable of receiving other pictures, which in their turn fade, without any possibility (so far as I can see) of arresting them; which is to be regretted, as they are very beautiful, and the paper of such easy preparation. If washed with ammonia or its carbonate, they are for a few moments entirely obliterated, *but presently reappear, with reversed lights and shades.* In this state they are fixed, and the ammonia, with all that it will dissolve, being removed by washing in water, their colour becomes a pure Prussian blue, which deepens much by keeping. If the solutions be mixed there results a very dark violet-coloured

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of the proto-ferrocyanuret of iron; the resumption of colour in the shade, to the re-oxidizement of this compound, which is well known to absorb oxygen from the air with avidity. Simple Prussian blue, however, is not whitened by the violet rays. Its state must be peculiar. (See Postscript.)

ink, which may be kept uninjured in an opake bottle, and will readily furnish, by a single wash, at a moment's notice, the positive paper in question, which is most sensitive when wet.

210. It seems at first sight natural to refer these curious and complex changes to the instability of the cyanic compounds, and that this opinion is to a certain extent correct, is proved by the photographic impressions described in Arts. 204 and 209, where no iron is added beyond what exists in the ferrocyanic salts themselves. Nevertheless the following experiments abundantly prove that in several of the changes above described, the *immediate action* of the solar rays is not exerted on these salts, but on the iron contained in the ferruginous solution added to them, which it deoxidizes or otherwise alters, thereby presenting it to the ferrocyanic salts in such a form as to precipitate the acids in combination with the peroxide or protoxide of iron, as the case may be. To make this evident, all that is necessary is *simply to leave out the ferrocyanate* in the preparation of the paper, which thus becomes reduced to a simple washing over with the ammonio-citric solution. Paper so washed is of a bright yellow colour, and is apparently little, but in reality highly sensitive to photographic action. Exposed to strong sunshine for some time indeed, its bright yellow tint is dulled into an ochrey hue, or even to gray, but the change altogether amounts to a moderate per centage of the total light reflected, and in short exposures is such as would easily escape notice. Nevertheless, if a slip of this paper be held for only four or five seconds in the sun (the effect of which is quite imperceptible to the eye), and when withdrawn into the shade be washed over with the ferrosesquicyanate of potash, a considerable deposit of Prussian blue takes place on the part sunned, and none whatever on the rest, so that on washing the whole with water, a pretty strong blue impression is left, demonstrating the reduction of iron in that portion of the paper to the state of protoxide. The effect in question is not, it should be observed, peculiar to the ammonio-citrate of iron. The ammonio- and potasso-tartrate fully possess, and the perchloride *exactly neutralized* partakes of the same property: but the experiment is far more neatly made and succeeds better with the other salts.

211. If a long strip of paper, prepared as in the last article, be marked off into compartments and subjected to graduated exposure to sunshine, so that the times of exposure in each succession shall form an arithmetical progression of 1^m, 2^m, &c., and when withdrawn washed over as aforesaid with the ferrosesquicyanuret and rinsed in water, the blue deposit is found to increase with the time of exposure up to a very deep and full colour, after which its total intensity, so far from increasing, diminishes, and at length almost vanishes. Again, if a slip of the same paper be exposed a long while to the spectrum, the whole impression consists in a feeble ochrey-brown streak, extending over the region of the blue, violet and lavender rays as far as about $+ 55$. But on the application of the cyanic solution (in the shade) a most intense blue spectrum is developed over the whole of the more refrangible region, in the interior of which the blue colour appears to have been, as it were, eaten away,

leaving a white oval, as in the specimen annexed; precisely the same phenomenon, in short, as would have been produced under the spectrum had the two liquids acted in conjunction. And this white portion comports itself under the influence of water or air, just as it would have done had it been produced under such joint action; i. e. it gradually turns blue till it is no longer distinguishable from the rest of the spectrum. It is also blued by ammonia, just as the positive paper of Art. 210, after bleaching, would be, &c. In short, it is evident that we have succeeded in separating the final action described in that article into two distinct steps or stages, the photographic influence being confined to the first, and the ferrosesquicyanate acting as a mere precipitant on the nascent compounds resulting from that influence.

212. In order to ascertain whether any portion of the iron in the double ammoniacal salt employed had really undergone deoxidation, and become reduced to the state of protoxide as supposed, I had recourse to a solution of gold, exactly neutralized by carbonate of soda. The proto-salts of iron, as is well known to chemists, precipitate gold in the metallic state. The effect proved exceedingly striking, issuing in a process no wise inferior in the almost magical beauty of its effect to the calotype process of Mr. Talbot, which in some respects it nearly resembles, with this advantage, as a matter of experimental exhibition, that the disclosure of the dormant image does not require to be performed in the dark, being not interfered with by moderate daylight. As the experiment will probably be repeated by others, I shall here describe it *ab initio*. Paper is to be washed with a moderately concentrated solution of ammonio-citrate of iron, and dried. The strength of the solution should be such as to dry into a good yellow colour, not at all brown. In this state it is ready to receive a photographic image, which may be impressed on it either from nature in the camera-obscura, or from an engraving on a frame in sunshine. The image so impressed, however, is very faint, and sometimes hardly perceptible. The moment it is removed from the frame or camera, it must be washed over with a neutral solution of gold of such strength as to have about the colour of sherry wine. Instantly the picture appears, not indeed at once of its full intensity, but darkening with great rapidity up to a certain point, depending on the strength of the solutions used, &c. At this point nothing can surpass the sharpness and perfection of detail of the resulting photograph. To arrest this process and to fix the picture (so far at least as the further agency of *light* is concerned), it is to be thrown into water very slightly acidulated with sulphuric acid and well soaked, dried, washed with hydrobromate of potash, rinsed, and dried again.

213. Such is the outline of a process to which I propose applying the name of *Chrysotype*, in order to recal by similarity of structure and termination the *Calotype* process of Mr. Talbot, to which in its general effect it affords so close a parallel. Being very recent, I have not yet (June 10, 1842) obtained a complete command over all its details, but the termination of the Session of the Society being close at hand, I have not thought it advisable to suppress its mention. In point of *direct*

sensibility, the Chrysotype paper is certainly inferior to the Calotype; but it is one of the most remarkable peculiarities of gold as a photographic ingredient, that *extremely feeble impressions once made by light, go on afterwards darkening spontaneously, and very slowly, apparently without limit, so long as the least vestige of unreduced chloride of gold remains in the paper**. To illustrate this curious and (so far as applications go) highly important property, I shall mention (incidentally) the results of some experiments made during the late fine weather, on the habitudes of gold in presence of oxalic acid. It is well known to chemists that this acid heated with solutions of gold precipitates the metal in its metallic state; it is upon this property that Berzelius has founded his determination of the atomic weight of gold. Light, as well as heat, also operates this precipitation; but to render it effectual, several conditions are necessary:—1st, the solution of gold must be neutral, or at most *very* slightly acid; 2nd, the oxalic acid must be added in the form of a neutral oxalate; and 3rdly, it must be present in a certain considerable quantity, which quantity must be greater, the greater the amount of free acid present in the chloride. Under these conditions, the gold is precipitated by light as a black powder if the liquid be in any bulk, and if merely washed over paper a stain is produced, which, however feeble at first, under a certain dosage of the chloride, oxalate, and free acid, goes on increasing from day to day and from week to week, when laid by in the dark, and especially in a damp atmosphere, till it acquires almost the blackness of ink; the unsunned portion of the paper remaining unaffected, or so slightly as to render it almost certain that what little action of the kind exists is due to the effect of casual dispersed light incident in the preparation of the paper. I have before me a specimen of paper so treated, in which the effect of thirty seconds exposure to sunshine was quite invisible at first, and which is now of so intense a purple as may well be called black, while the unsunned portion has acquired comparatively but a very slight brown. And (which is not a little remarkable, and indicates that in the time of exposure mentioned the *maximum* of effect was attained) other portions of the same paper exposed in graduated progression for longer times, viz. 1^m, 2^m, and 3^m, are not in the least perceptible degree darker than the portion on which the light had acted during thirty seconds only.

214. The very remarkable phenomenon described in Art. 208. of a second darkening, different in character and colour, coming on after the bleaching effect of solar light has been fully completed, is not without a parallel among the argentine compounds. I refer to the action of the hydriodic salts on argentine papers completely blackened by exposure to sunshine, an action imperfectly described in § 5. of my former paper (Art. 94 *et seq.*), and signalized as to one of its most striking peculiarities in Note 2, Art. 129. of that communication. To study the phenomena of this action in their simplest form, a paper prepared without iodine, and of a positive

* Subsequent experiments have convinced me that this property cannot be taken advantage of to increase the intensity of the chrysotype impression, however it may be available in other processes. Note added during the printing, J. F. W. H.

character is required. The simplest and most convenient is that prepared by Mr. Hunt with one wash of muriate of ammonia, two of nitrate of silver*, and exposure to sunshine. With such paper (obligingly furnished me by Mr. Hunt himself) I made the following experiments.

215. Exposed to the spectrum and washed with a solution of hydriodate of potash too weak fully to excite it†, two contrary actions were produced by the rays above and below the zero point or mean yellow. By the former the paper began to be bleached at a point distant + 26·5 parts from the zero, from which point the bleaching extended gradually upwards to a considerable distance, and downwards to the circumference of a semicircle, having that point for a centre. By the latter the paper was darkened (at least in comparison with its general surface, which, purposely subjected to dispersed light, had begun to lose much of its original intense blackness), the darkness spreading also upwards and downwards: upwards till it passed the zero point, and nearly or quite attained the semicircle above mentioned; and downwards to about − 19, or − 20 parts. As the paper dried the action seemed to be suspended. It became therefore necessary to renew the hydriodic wash, and thereby to increase the actual quantity of that salt present on the paper. Both actions grew more intense, but the bleaching effect most so. A perfect semicircle and long cometic train, *c*, *d*, fig. 12, No. 1, was produced, within which space the blackness of the paper was totally destroyed, and replaced by white or rather very pale yellow. The hydriodic washes being again and again renewed, the darkness at first produced in the lower part of the spectrum began to give way, and was slowly replaced by a very feeble bleaching, which at length extended very far indeed below the extreme red rays, and upwards to join the semicircle C fig. 12, No. 2, which had by this time assumed an outline perfectly sharp and well-defined, having its centre on the original point + 26·5 of its commencement. But *within* this semicircle and its train, remarkable changes were observed to be all the while in progress. First, a somewhat dark, and greyish or brownish, perfectly circular and well-defined solar image arose, its diameter being somewhat less than that of the semicircular terminations, *so as to leave a clear and distinct white border all around it*, as represented by the dotted line in fig. 12, No. 2. Shortly after the complete formation of this spot, i. e. after its circular outline could be distinctly traced all round, it began to extend itself upwards into an oval or tailed form, but preserving its circular shape below and maintaining the white border inviolate, assuming at the same time a brownish yellow colour which gradually deepened, but never became intense. At the same time a very remarkable change was observed to take place in the reflective (or absorbent) powers of the paper in this region. The violet-coloured end of the spectrum, which hitherto had been distinctly seen as usual occupying the space from + 30 to + 40·6, became quite indiscernible, while on the other hand the blue rays adjoining became reflected with such co-

* Muriate of ammonia forty grains, water four ounces; nitrate of silver sixty grains, water one ounce.

† Ioduret of potassium sixty grains, water one ounce.

piousness as to terminate the spectrum by a well-defined semicircle *e*, fig. 12, No. 3, and to give to the whole portion *c e* the appearance of a brilliant and purely blue spot. Finally, after long-continued action, the interior browned oval above-mentioned was found to have been prolonged into a figure of the form No. 4, fig. 12 (distinctly seen at the *back* of the paper), of which the termination by a narrow neck and circular enlargement indicates the definite action of a ray much further removed along the axis of the spectrum. Washing with water at once obliterates this part of the phenomenon, destroys the brown colour, and leaves simply the bleached cometic train, in singularly striking contrast with the dark ground of the paper. Specimens of the spectrum itself are subjoined for inspection.

216. The black positive paper used in the above experiment (which has been often repeated with the same results) contains free nitrate of silver. If this be washed out, the darkening at the lower end of the spectrum is not produced, but in its place the feeble subsequent bleaching in the region above-mentioned commences at once. And if besides washing with mere water, the paper be subsequently washed with a neutral hyposulphite to remove all chloride of silver, it is reduced to a state of perfect insensibility. It is therefore to this latter element that the direct action of the bleaching rays is to be referred. A few months' keeping also destroys the positive sensibility of the paper in question entirely.

J. F. W. Herschel.

Collingwood,
June 13, 1842.

Postscript added August 29, 1842.

217. I gladly avail myself of the permission accorded by the President and Council to append to this communication, in the form of a Postscript, some additional facts illustrative of the singular properties of iron as a photographic ingredient, which have been partially developed in the latter articles of it, as well as an account of some highly interesting photographic processes dependent on those properties, which the superb weather we have lately enjoyed has enabled me to discover, as also to describe a better method of fixing the picture, in the process to which I have given the name of *Chrysotype*; that described in Art. 212. proving insufficient. The new method (in which the hydriodate is substituted for the hydrobromate of potash) proves perfectly effectual; pictures fixed by it not having suffered in the smallest degree, either from long exposure to sunshine, or from keeping; alone, or in contact with other papers. It is as follows:—As soon as the picture is satisfactorily brought out by the auriferous liquid (Art. 212.) it is to be rinsed in spring water, which must be three times renewed, letting it remain in the third water five or ten minutes. It is then to be blotted off and dried, after which it is to be washed on both sides with a somewhat

weak solution of hydriodate of potash. If there be any free chloride of gold present in the pores of the paper, it will be discoloured, the lights passing to a ruddy brown; but they speedily whiten again spontaneously, or at all events, on throwing it (after lying a minute or two) into fresh water, in which, being again rinsed and dried, it is now perfectly fixed.

218. If paper prepared as above recommended for the chrysotype, either with the ammonio-citrate or ammonio-tartrate of iron, and impressed, as in that process, with a latent picture, be washed with nitrate of silver instead of a solution of gold, a very sharp and beautiful picture is developed, of great intensity. Its disclosure is not instantaneous; a few moments elapse without apparent effect; the dark shades are then first touched in, and by degrees the details appear, but much more slowly than in the case of gold. In two or three minutes, however, the maximum of distinctness will not fail to be attained. The picture may be fixed by the hyposulphite of soda, which alone, I believe, can be fully depended on for fixing argentine photographs.

219. *Cyanotype.*—If a nomenclature of this kind be admitted (and it has some recommendations), the whole class of processes in which cyanogen in its combinations with iron performs a leading part, and in which the resulting pictures are blue, may be designated by this epithet. The varieties of cyanotype processes seem to be innumerable, but that which I shall now describe deserves particular notice, not only for its pre-eminent beauty while in progress, but as illustrating the peculiar power of the ammoniacal and other persalts of iron above mentioned to receive a latent picture, susceptible of development by a great variety of stimuli. This process consists in simply passing over the ammonio-citrated paper on which such a latent picture has been impressed, *very sparingly and evenly*, a wash of the solution of the common yellow ferrocyanate (prussiate) of potash*. The latent picture, if not so faint as to be quite invisible (and for this purpose it should not be so), is negative. As soon as the liquid is applied, which cannot be in too thin a film, the negative picture vanishes, and by very slow degrees is replaced by a positive one of a violet-blue colour on a greenish yellow ground, which at a certain moment possesses a high degree of sharpness and singular beauty and delicacy of tint. If at this instant it be thrown into water, it passes immediately to Prussian blue, losing at the same time, however, much of its sharpness, and sometimes indeed becoming quite blotty and confused. But if this be delayed, the picture, after attaining a certain maximum of distinctness, grows rapidly confused, especially if the quantity of liquid applied be more than the paper

* Vulgarly, and in my opinion very conveniently and *correctly* so called, according to the true intent and meaning of SCHEELE. Trivial names for common objects are to be maintained and defended on principles far more general than systematic nomenclature. For this reason I trust never to see the name muriatic give way to hydrochloric, or nitric thrust aside for azotic acid. The *prussic acid* is that acid, whatever it be, which, united with oxide of iron as a base, forms *Prussian blue*, from which remarkable compound the whole history of cyanogen originated. The now ascertained existence of another ferrocyanate makes this recurrence to a trivial name for the vulgar one more necessary.

can easily and completely absorb, or if the brush in applying it be allowed to rest on, or be passed twice over any part. The effect then becomes that of a coarse and ill-printed wood-cut, all the strong shades being run together, and a total absence prevailing of half lights.

220. To prevent this confusion, gum-arabic may be added to the prussiated solution, by which it is hindered from spreading unmanageably within the pores of the paper, and the precipitated Prussian blue allowed time to agglomerate and fix itself on the fibres. By the use of this ingredient also, a much thinner and more equable film may be spread over the surface ; and *when perfectly dry*, if not sufficiently developed, the application may be repeated. By operating thus I have occasionally (though rarely) succeeded in producing pictures of great beauty and richness of effect, which they retain (if not thrown into water) between the leaves of a portfolio, and have even a certain degree of fixity—fading in a strong light and recovering their tone in the dark. The manipulations of this process are, however, delicate, and complete success is comparatively rare.

221. If sulphocyanate of potash be added to the ammonio-citrate or ammonio-tartrate of iron, the peculiar red colour which that test induces on persalts of the metal is not produced, but appears at once on adding a drop or two of dilute sulphuric or nitric acid. This circumstance, joined to the perfect neutrality of these salts, and their power, in such neutral solution, of enduring, undecomposed, a boiling heat, contrary to the usual habitudes of the peroxide of iron*, together with their singular transformation by the action of light to proto-salts, in apparent opposition to a very strong affinity, has, I confess, inclined me to speculate on the possibility of their ferruginous base existing in them, not in the ordinary form of peroxide, but in one isomeric with it. The non-formation of Prussian blue, when their solutions are mixed with prussiate of potash (Art. 209.), and the formation in its place of a deep violet-coloured liquid of singular instability under the action of light, seems to favour this idea. Nor is it altogether impossible that the peculiar "prepared" state superficially assumed by iron under the influence of nitric acid, first noticed by Keir, and since made the subject of experiment by M. Schönbein and myself†, may depend on a change superficially operated on the *iron itself* into a new metallic body isomeric with iron, unoxidable by nitric acid, and which may be considered as the radical of that peroxide which exists in the salts in question, and possibly also of an isomeric protoxide. A combination of the common protoxide with the isomeric peroxide, rather than with the same metal in a simply higher stage of oxidation, would afford a not unplausible notion of the chemical nature of that peculiar intermediate oxide to which the name of "Ferroso-ferric" has been given by Berzelius. If (to render my meaning more clear) we for a moment consent to designate such an isomeric form of iron by the name siderium, the oxide in question might be regarded as a sideriate of iron. Both

* See my paper on this subject in Philosophical Transactions, cxi. p. 293.

† See Annales de Chimie, tom. liv. p. 87.

phosphorus and arsenic (bodies remarkable for sesqui-combinations) admit isomeric forms in their oxides and acids*. But to return from this digression.

222. If to a mixture of ammonio-citrate of iron and sulphocyanate of potash a small dose of nitric acid be added, the resulting red liquid spread on paper spontaneously whitens in the dark. If more acid be added till the point is attained when the discoloration begins to relax, and the paper when dry retains a considerable degree of colour, it is powerfully affected by light, and receives a positive picture with great rapidity, which, like the guaiacum impression noticed in Art. 154, appears at the back of the paper with even more distinctness than on its face. The impression, however, is pallid; fades on keeping, nor am I acquainted at present with any mode of fixing it.

223. If paper be washed with a mixture of the solutions of ammonio-citrate of iron and ferrosesquicyanate of potash, so as to contain the two salts in about equal proportions, and being then impressed with a picture, be thrown into water and dried, a negative blue picture will be produced agreeably to what is stated in Art. 154. This picture I have found to be susceptible of a very curious transformation, preceded by total obliteration. To effect this it must be washed with solution of proto-nitrate of mercury, which in a little time entirely discharges it. The nitrate being thoroughly washed out and the picture dried, a smooth iron is to be passed over it, somewhat hotter than is used for ironing linen, but not sufficiently so to scorch or injure the paper. The obliterated picture immediately reappears, not blue, but brown. If kept for some weeks in this state between the leaves of a portfolio, in complete darkness, it fades, and at length almost entirely disappears. But what is very singular, a fresh application of the heat revives and restores it to its full intensity.

224. This curious transformation is instructive in another way. It is not operated by light, at least not by light alone. *A certain temperature* must be attained, and that temperature suffices in total darkness. Nevertheless, I find that on exposing to a very concentrated spectrum (collected by a lens of short focus) a slip of paper duly prepared as above (that is to say, by washing with the mixed solutions, exposure to sunshine, washing, and discharging the uniform blue colour so induced as in the last article), its whiteness is changed to brown over the whole region of the red and orange rays, *but not beyond* the luminous spectrum. Three conclusions seem unavoidable;—1st, that it is the heat of these rays, not their light, which operates the change; 2ndly, that this heat possesses a peculiar chemical quality which is not possessed by the purely calorific rays outside of the visible spectrum though far more intense; and, 3rdly, that the heat radiated from obscurely hot iron, abounds especially in rays analogous to those of the region of the spectrum above indicated. And there are the very same conclusions derived from the experiments on guaiacum in Art. 158—160.

* The latter from the late experiments and remarks of Rose on the vitreous state of the arsenious acid and its luminosity in crystallizing from acid solutions.

225. Whatever be the state of the iron in the double salts in question, its reduction by blue light to the state of protoxide is indicated by many other reagents. If, for example, a slip of paper, prepared with the ammonio-citrate and partially sunned, be washed, when withdrawn, with bichromate of potash, the bichromate is deoxidized and precipitated on the sunned portion, just as it would be if directly exposed to the sun's rays. Every reagent in short which is susceptible of being deoxidated, wholly or in part, by contact with the protoxide of iron, is so also by contact with the sunned paper. Taking advantage of this property, I have been enabled to add another and very powerful element to the list of photographic ingredients.

226. *Photographic Properties of Mercury.*—This element is mercury. As an agent in the Daguerreotype process, it is not, strictly speaking, photographically affected. It operates there only in virtue of its readiness to amalgamate with silver, properly prepared to receive it. That it possesses *direct* photographic susceptibility, however, in a very eminent degree, is proved by the following experiment. Let a paper be washed over with a weak solution of periodide of iron, and when dry with a solution of proto nitrate of mercury. A bright yellow paper is produced, which (if the right strength of the liquids be hit) is exceedingly sensitive while wet, darkening to a brown colour in a very few seconds in the sunshine. Withdrawn, the impression fades rapidly, and the paper in a few hours recovers its original colour. In operating this change of colour the whole spectrum is effective, with the exception of the thermic rays beyond the red.

227. Proto-nitrate of mercury simply washed over paper is slowly and feebly blackened by exposure to sunshine. And if paper be impregnated with the ammonio-citrate, already so often mentioned, partially sunned, and then washed with the proto-nitrate, a reduction of the latter salt, and consequently blackening of the paper takes place very slowly in the dark over the sunned portion, to nearly the same amount as in the direct action of the light on the simply nitrated paper.

228. But if the mercurial salt be subjected to the action of light in contact with the ammonio-citrate, or tartrate, the effect is far more powerful. Considering, at present, only the citric double-salt, a paper prepared by washing first with that salt and then with the mercurial proto-nitrate (drying between) is endowed with considerable sensibility, and darkens to a very deep brown, nay to complete blackness, on a moderate exposure to good sun. Very sharp and intense photographs of a negative character may be thus taken. They are however difficult to *fix*. The only method which I have found at all to succeed, has been by washing them with bichromate of potash and soaking them for twenty-four hours in water, which *dissolves out* the chromate of mercury for the most part, leaving however a yellow tint on the ground, which resists obstinately. But though pretty effectually fixed in this way against *light*, they are not so against *time*, as they fade considerably on keeping.

229. When the proto-nitrate of mercury is mixed, in solution, with either of the ammoniacal double salts, it forms a precipitate, which, worked up with a brush to the

consistency of cream, is easily (and with certain precautions of manipulation*) very evenly spread on paper, producing photographic tablets of every variety of sensibility and inertness, according to the proportion of the doses used. By combining all three of the ingredients, and adding a small quantity of tartaric acid†, a paper is produced of a pretty high degree of sensibility (more than by the use of either separately), which in about half an hour or an hour, according to the sun, affords pictures of such force and depth of colour, such velvety richness of material, and such perfection of detail and preservation of the relative intensities of the light, as infinitely to surpass any photographic production I have yet seen, and which indeed it seems impossible to go beyond. Most unfortunately, they cannot be preserved. Every attempt to fix them has resulted in the destruction of their beauty and force; and even when kept from light, they fade with more or less rapidity, some disappearing almost entirely in three or four days, while others have resisted tolerably well for a fortnight, or even a month. It is to an over-dose of tartaric acid that their more rapid deterioration seems to be due, and of course it is important to keep down the proportion of this ingredient as low as possible. But without it I have never succeeded in producing that peculiar velvety aspect on which the charm of these pictures chiefly depends, nor anything like the same intensity of colour without over-sunning.

230. I might here describe many other curious and interesting photographic results to which, under the genial influence of such a summer as, possibly, has never before been witnessed in England, I have been conducted. But in so doing I should surpass the reasonable bounds of a Postscript illustrative of my text, and abuse the privilege accorded me. Yet I cannot forbear noticing one at least, in which a line or dot engraving of any degree of delicacy is imitated, line for line, and dot for dot in a manner which might deceive any but a practised artist to the point of rendering him unable to declare that the photograph had *not* been struck off from the original plate with common printing ink, by the ordinary process of copper-plate printing. The details of this process, which are delicate and somewhat tedious, cannot properly be stated here; if for no other reason, because I have not yet obtained a complete command over the result: but a microscopic examination of the specimens placed in the hands of our worthy Secretary, though somewhat marred by the accidents of manipulation, will I think suffice to justify the terms employed above.

* The cream should be spread as rapidly as possible over the whole paper, well worked in, cleared off as much as possible, and finished with a brush nearly dry, spread out broad and pressed to a strait thin edge, which must be drawn as lightly and evenly as possible over every part of the paper till the surface appears free from every streak, and barely moist.

† One measure of a solution of ammonio-citrate, and one of a solution of ammonio-tartrate of iron, containing, each, one-tenth of its weight of the respective salts. Tartaric acid, saturated solution, one-eighth of the *joint volumes* of the other solutions. Form a cream by pouring in as rapidly as possible one measure of a saturated solution of the proto-nitrate and well mixing with a brush.

XIII. *On the Organic Tissues in the Bony Structure of the Corallidæ.*

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THE polyps of the numerous species of the Corallidæ have been known and described many years, but I am not aware that their connection with each other has been traced through the solid masses of their calcareous skeletons, or that the nature and structure of the animal tissues of these parts have, to the present period, been figured or described by any author. Ellis, in his History of Corallines, published in the year 1755, has described the mode he adopted in the examination of the calcareous axes of some of the subjects of his observations, and has mentioned in several places in his work, that he had subjected them to the action of vinegar, but he does not in any instance minutely describe the results obtained by this application, nor does he describe any organic tissues or results, further than that he thus obtained the animal substance of the skeleton, freed from the calcareous matter previously combined with it. That so accurate, acute and industrious an observer, should not have seen and described more of the minute organic tissues which are now with our improved means readily to be distinguished in the tribe of animals that formed the objects of his investigations, is only to be accounted for by the want of instruments competent to observe tissues of such extreme delicacy.

My attention has been drawn to this subject from having ascertained, in one of the sponges of commerce, and in several species of sponges from Australia, the existence of a very minute and beautifully ramified vascular tissue; and in some cases of the occurrence of molecules of extreme minuteness within those vessels which appeared to me to be analogous to those of the circulation in the higher tribes of animals. These facts I had the honour of laying before the Microscopical Society of London, on the 27th of January 1841. The occurrence of such tissues in the horny skeletons of animals so low in the organic scale as the Spongiadæ, naturally suggested the idea of the probability of the occurrence of similar or more fully developed tissues in the skeletons of the higher tribes of zoophytes; and I accordingly determined to pursue the investigation, with the hope of adding, in some slight degree, to our knowledge of the organic structure of the bony portions of the Corallidæ, and also of throwing, if possible, further light upon the still contested place in the scale of created beings of the sponge tribe. With this view, I submitted small portions of nearly seventy species of bony corals to the action of dilute muriatic acid, and from thirty-five of these I have succeeded in obtaining the animal tissues in a

sufficiently perfect state to allow of a full and satisfactory view of their structure, and in many instances, the results of these examinations have been singularly interesting. I will not detail in succession the whole of these researches, but select from them such only as afford the best specimens of the tissues I am about to describe. The mode I have adopted in the examination of these specimens has been, to separate small pieces, about the quarter of an inch in diameter, from as nearly the termination of the branches or other extremities of the coral as possible, as being the most likely to have the animal tissues in their most perfect and efficient states, and to immerse these pieces in a solution of the common muriatic acid of commerce, in twelve or fifteen times its bulk of water. After the effervescence has ceased, the animal matter is usually found floating upon the surface of the fluid, in the form of an exceedingly delicate flocculent mass. This may then be removed, with as little alteration of form as possible, into some clean water in a watch-glass; a small portion, about the one-tenth of an inch in diameter, should be taken from the mass with a fine pair of scissors, and placed in a drop of water upon a slip of glass, covered with a piece of very thin glass or mica.

Upon treating in this manner some small pieces of *Millepora alcicornis*, I obtained the animal matter in an exceedingly favourable state for examination. When this was viewed by transmitted light with a power of 200 linear, the mass appeared to be composed of thin glutinous animal membranes, which frequently assumed a sacculated appearance, probably caused by their having been moulded into this shape by the polyp cells of the coral. Amid this tissue there was dispersed a complex reticulated vascular tissue, floating freely between the layers of membrane, and dividing and anastomosing without any appearance of regularity. The largest of these vessels averaged $\frac{1}{5000}$ of an inch in diameter, the smaller ramifications being about half that size. Those of the greatest diameter were by no means regularly cylindrical, but threw off at short intervals numerous short cæcoid appendages, varying in length from merely tubercular projections to eight or ten times their diameters, and terminating hemispherically without any previous diminution of size. From these causes, the ends of such vessels frequently assume the ramified appearance of a Deer's horn (Plate XVI. fig. 1); other branches, instead of ending in this manner, continue dividing and subdividing until they also terminate in exceedingly minute ramifications, many of which do not exceed $\frac{1}{20,000}$ of an inch in diameter.

If we follow these vessels towards their larger extremities, we observe that they become more regularly cylindrical than that portion of them represented by figure 1, and at last they terminate in large cylindrical vessels of about $\frac{1}{3000}$ of an inch in diameter.

The smaller vessels usually enter the larger one by pairs, and a considerable increase of the diameter of the latter takes place in the immediate vicinity of the joining vessels, at the mouth of each of which there is situated a valve or diaphragm, as represented at *a*, *a*, fig. 2. The great vessel also has a valve at *b*, fig. 2. The course

of these large cylindrical vessels may be traced for a considerable distance, and many similar junctions of the large and small tissues be observed. They do not always join the larger so precisely opposite to each other as in the instance figured; but in all the cases observed, the valves in each of the tissues were present, although not always in the same relative position in the large vessel, being sometimes on the contrary side of the mouths of the smaller ones to that represented in the figure. Occasionally, but very rarely, a valve is to be seen in the larger vessels where no junction with the smaller ones takes place.

I have been unable to trace the large vessels to their natural terminations, but it is probable that they originate at the bases of the polyp cells, and that the valves with which they are furnished, were designed by nature to prevent the retrocession of the chyle, elaborated in the digestive organs of the polyps; and this idea is strengthened by circumstances which I shall hereafter describe.

The difference in the structure and characters of the larger and the smaller of these vascular tissues would seem to indicate that they have separate and distinct functions; in the former we observe them maintaining a uniform diameter throughout a long course without once branching or dividing, while the latter immediately decreases in size, dividing and subdividing until they terminate in vessels of extreme minuteness. The valvular structure is also a character peculiarly distinctive of the larger system; as there is not the slightest indication of such organs in the smaller vessels throughout the whole of their course, subsequent to their junction with the larger tissue. Several other corals that I examined exhibited this valvular tissue with very little variation in its character from that of *Millepora alcicornis*, but in one specimen (*Cellepora pumicosa*) it differs in so great a degree as to render a description of it necessary. Instead of being of an uniform character, and pursuing an unbroken course for a considerable length, as in *Millepora alcicornis*, it varied continually in its size, contracting in some parts to half or a third of the diameter that it exhibited at others, and especially so at the parts where the valves are situated, as represented at *a*, *b*, and *c*, fig. 3. Sometimes, as at the point *a*, fig. 4, it is terminated by an abrupt runcation and a slight lateral expansion. At each of these parts there is a valve and a new branch produced. In some cases, as at *d*, fig. 3, there is but a single branch given off with the usual valves in the branch and main trunk; and in others, as at *b*, fig. 4, there is the same form of structure observed which is so characteristic of this description of vessel in *Millepora alcicornis*. The branches given off in all the cases figured from the Cellepora were not belonging to the fine complex system of vessels, but of the same nature as the parent ones, giving off secondary branches, as represented at *c*, fig. 4, which have the valvular structure in every respect like the main vessel. I could not trace the connection between this valvular system of vessels and the minute contorted system with cæcoid projections, although the latter was present in abundance; but it may be fairly presumed from the result of the examination of the Millepora, that such a junction does take place. About the same propor-

tions are observed between the two descriptions of vessels as in the former case, but in the Cellepora both the tissues are much more minute than those in *Millepora alcicornis*; the average diameter of the larger vessel is $\frac{1}{5000}$ of an inch. Upon submitting some fragments of *Pavonia Boletiformis* to the action of dilute acid, and examining the animal matter thus obtained, the same description of membranous structure was observed, and a similar fine complex vascular tissue exhibiting irregularities of the structure, and in other respects so closely resembling that observed in *Millepora alcicornis* as to render a further description of it unnecessary. The larger kind of vessels were also present in about the same proportion as in Millepora, but they differed from them in some respects, inasmuch as towards their outer extremities they resolved themselves into a much greater number of branches, all originating at nearly the same point, as represented at *a*, fig. 5, and frequently clustered together in such a manner as closely to resemble the distorted tentacula of a dead polyp; but I do not believe that they are in reality the remains of those organs, but rather of the great ducts that have terminated at the bases of the polyps; as we find in many instances branches given off from their sides, which are surmounted by elliptical ovoid bodies, as represented in fig. 6, which have much the appearance of being incipient polyps, or gemmules which had not been projected beyond the outer surface of the coral. These bodies are divided at right angles to their axes by two or three diaphragms, and present in other respects a cellulated appearance. They occur in considerable numbers dispersed amid the tissues, and vary in size from $\frac{1}{2000}$ to $\frac{1}{500}$ of an inch in length. The branches are all of them divided at short intervals by diaphragms, so as to assume a cellulated appearance, the diaphragms becoming more distant from each other as they recede from the apex of the branch; and they are continued to some distance below the point where the branches are given off from the parent vessels, until at last they cease to appear, and the tissue assumes its usual vascular character. The average diameter of these vessels is $\frac{1}{5000}$ of an inch.

Beside the elliptical bodies, there are frequently to be seen large spherical or oval brown masses (fig. 7), whose diameter averages $\frac{1}{400}$ of an inch. They are nearly opake, but when a bright stream of light is transmitted through their substance, they are seen to be filled with irregular cellular structure, or closely compressed granular matter. They appear always to be attached to, or to be partially imbedded in, the membrane, and are connected with each other by a beautiful moniliform tissue. When these vessels terminate at the masses, they do not abruptly enter its substance, but, dividing into minute ramifications, are spread over and lost upon its surface, as at *a*, fig. 7. In other cases they do not divide in this manner, but, preserving their integrity, they attach themselves to the surface, and, passing over a third or half of its diameter, detach themselves and resume their course, as represented at *b*, fig. 7. It is difficult to conceive the nature and purposes of these curious masses, but they bear a striking analogy to "the brown bodies" described by my

friend Dr. ARTHUR FARRE, in his paper on the Structure of the Ciliobrachiate Polypi, in the Philosophical Transactions for 1837, p. 400, where he describes and figures them as occurring in the bases of the polyp cells. He conjectures that they are probably connected with the reproduction of the species. In many parts of the membranous structure of this coral, there appear numerous minute acicular double-pointed siliceous spicula, which do not exceed $\frac{1}{1000}$ of an inch in length, and $\frac{1}{12,500}$ of an inch in diameter. They are disposed without order, and are not to be found in every part of the membrane, but only in small groups at comparatively considerable intervals. Beside these minute spicula, there are others which occur sparingly dispersed amid the tissues, and which are of a different form and of much greater dimensions. The average size is $\frac{1}{90}$ of an inch in length, and $\frac{1}{4000}$ in diameter, and they are very much in form and proportions like a common brass pin, terminating at one extremity in a point, and at the other in a spherical head, and are well represented by the spicula in fig. 8, which were found imbedded amid the tissues of a species of Anthopora which I shall presently describe. These larger spicula were occasionally studded with a few tubercles, and in this as in other respects were so precisely similar to the spicula of this description, which are so abundant in some species of Halichondria and other genera of the Spongiadæ, as to render it impossible to distinguish the one from the other, when separated from the respective bodies that have produced them. Upon examining the animal matter obtained from a species of Anthopora, the membranous tissue appeared as abundant as in the former cases, but somewhat denser in structure. The smaller tissue of vessels was present, although very indistinctly to be seen in parts between the membranes. The larger described vascular tissue was not detected in the portions subjected to examination. The principal features in this coral are the great abundance of large pin-shaped siliceous spicula, such as I have described as existing sparingly dispersed in the coral last referred to, and the occurrence of a profusion of the nuclei of ROBERT BROWN, or cytoblasts of SCHLEIDEN, which were dispersed over all parts of the membranous structure, as represented in fig. 8. In some parts of the tissue they were in greater abundance than in others, and especially so when a cluster or fasciculus of vessels appeared to be seated beneath them; and from this cause probably they also sometimes resolve themselves into lines, curved or straight, consisting of eight or ten cytoblasts in succession. These interesting and curious organs were found imbedded in the membranous tissues of almost every coral that I submitted to examination. In the Anthopora they were nearly uniform in size, and about $\frac{1}{2500}$ of an inch in diameter, but in other specimens they varied greatly in their dimensions. Their mode of disposition is also exceedingly various. Sometimes they occur singly and at long intervals; at others, as in Anthopora, Plate XVI. fig. 8, in great abundance, and with but faint traces of order or arrangement; while in other cases, as in *Millepora alcicornis*, they are disposed in circular groups, or in lines composed of a single series, which branch off and divide in such a manner as strongly to impress upon the mind

of the observer the idea, that this mode of disposition could have obtained only in consequence of their having been originated within the parietes of vascular tissue (Plate XVII. fig. 1). At the same time I must state, that I have examined many such branching series of these organs without being able to detect any remains of the supposed vascular tissue, which it is possible may have been absorbed after having performed the office for which it was produced; and this view of their origin is the more probable, as we observe, in many cases, the minute vascular tissue, so abundantly dispersed amid the whole of the membranous structure, frequently filled either with continuous threads of a glutinous looking matter, or of an abundance of minute detached molecules, and in one instance, represented in Plate XVII. fig. 2, I observed a series of molecules, with a few minute cytoblasts intermixed, continued beyond an irregular and indistinct termination of a vessel, no part of the parietes of which could be detected around any portion of the line of molecules and cytoblasts.

Whatever may be the origin of the cytoblasts, it is sufficiently apparent that their office is that of the production and renovation of the cellular membranous structures of the bodies in which they appear.

Upon examining the animal matter obtained from *Agaricia ampliata*, I found them developing cellular tissue upon all parts of the membrane, spreading thinly over the surface of the tissue, and, when several of them were situated together, assuming the appearance of a rude reticulated epidermal tissue.

One of the most interesting of their modes of developing tissue was seen upon examining the animal matter obtained from *Cellepora pumicosa*. The membranous tissue is exceedingly thin and even in its structure, beautifully diaphanous, and abounds in large sacculated projections (as represented in Plate XVII. fig. 3). At the termination of each of these we observe a cytoblast, which is attached to the surrounding membrane by the outer circle of its disc, from all parts of which it has projected the thin filmy tissue in a backward direction, thus producing the elongated sacculated organ upon the summit of which it is seated, and causing its apex frequently to assume a truncated or flattened appearance. The sacs may be seen in every degree of development from the cytoblast, scarcely elevated above the surface of the membrane, until they are projected to the extent of eight or ten times the amount of their own diameter. The projection of the sac is usually in the direction of a straight or slightly curved line; occasionally it forms an abrupt elbow; but in all cases the cytoblast retains its place at the extremity of the organ. Sometimes, but very rarely, there are two cytoblasts at the apex, which, having operated simultaneously, cause the organ to assume an oval instead of a cylindrical form. When the apices of two of these sacs meet, as represented at *a*, Plate XVII. fig. 3, they coalesce and appear to form a permanent union, but I have not observed that this takes place when they impinge upon any other part of the sac.

As the sac elongates, we frequently find it accompanied by minute vessels, which usually but not universally, assume a spiral direction, as seen at *b*, Plate XVII. fig. 3,

and in fig. 4. These vessels appear to be part of a system of minute vascular tissue peculiar to these organs, as they differ in character from the minute vascular tissue that we have before described as prevailing almost universally in the animal matter of the Corallidæ, being furnished with valves or diaphragms at regular intervals. But the most singular circumstance is that they appear to demonstrate the fact, that cytoblasts are not only concerned in the production of the cellular structure, but that they are also the direct originators of the vascular tissue, for in this case we observe short branches given off at nearly right angles from the minute vessels, and at the apex of each of these there is seated a small cytoblast, not exceeding $\frac{1}{7143}$ of an inch in diameter, but very considerably larger than the branch that supports it, which measured but $\frac{1}{14300}$ of an inch in diameter. Other small cytoblasts are seated upon the vessels, as shown in fig. 4, which represents one of the sacs with the accompanying vessels and cytoblasts, as seen with a microscopic power of 800 linear. The vessels are not attached to the sacs throughout the whole of their course; considerable portions of them are floating freely between the organs; and branches from these free vessels are often to be seen passing in a very singular manner half round the outer circle of the cytoblast at the apex of the sac, and, upon quitting it, proceeding to another and embracing it in a similar manner: indeed, the apices of by far the greater number of them are thus visited by branches of the vessel. It is difficult to imagine the purpose of the connection between them, but it is evident that the two organs are connected in their operations, whatever they may be.

The result of the examination of two specimens of Nullipora from Australia, which appeared to be of the same species, was exceedingly interesting. The cellular structure was developed in the most perfect and beautiful manner in both of them. The greater number of cells were empty, transparent, and in a slight degree larger at one end than at the other. At the smaller extremity of each there is most frequently a cytoblast, which is usually as pellucid and transparent as the walls of the cell, but in other cases it is full of a brown and indistinctly granulated matter, as represented in Plate XVII. fig. 5, which exhibits a view of the ends of the cells with the cytoblasts in this state, while fig. 6 represents a longitudinal view of the same structure in its transparent state. In this position the cytoblasts are not at all times to be seen.

In the second of the specimens examined, there was an abundance of fine membrane, with a quantity of a glutinous-looking matter adhering in irregular patches to its surface, and of the complex vascular tissue with the cæcoid appendages; thus assimilating the general character of its structure in a very close degree to that of the true Corallidæ. Although in many parts of its cellular structure it exhibits an appearance very much like that of some succulent vegetables, yet there are others in which this similarity does not obtain, and where the cells are so loosely disposed as to preserve nearly a cylindrical form (Plate XVII. fig. 7), and to assume very much the appearance of the cells of the fatty tissues in the higher class of animals: while the perfect identity of the character of the vascular tissue with that of the true corals,

combined with the glutinous animal-looking membrane, without even the slightest appearance of reticulated structures, strongly impresses the feeling upon the mind that this disputed genus is in truth animal and not vegetable, as we have been led to believe up to the present period.

An examination of our British species, *Nullipora calcarea*, assists in the confirmation of the animal view of the subject, as in this we find the cellular structure in a much less perfect and regular condition than in the Australian specimens, while the vascular tissue, with cæcoid appendages, and the membrane, are almost identical with those of the Australian Nullipora.

The animal matter obtained from an undescribed species of Agaricia, nearly allied to *Agaricia ampliata*, exhibited a form of tissue that I have not observed in any other coral. The membranous structure and the minute vessels with cæcoid appendages presented the usual characters, but the latter were not so abundant as in many of the specimens I have examined. The remarkable feature is the presence of numerous elongated vesicles, which are coated with a fine fibrous tissue regularly disposed in diagonal or waved lines across them, as represented in Plate XVII. fig. 8. Some of these organs have one or more angles in a longitudinal direction, extending from the base to the apex of the vesicle, while others have the appearance of being cylindrical sacs. They appear to be attached to the membrane throughout their whole length, as neither of their extremities is projected from the plane of the surrounding tissues. But from the different aspect of the two extremities, it is evident that they have their origin from the end and not the side of the vesicle, one termination generally being ill-defined and appearing to merge in the surrounding membrane, while the opposite one is distinctly visible. The fibrous threads of the vesicle do not pass from the one to the other, nor do they appear to originate in the membrane upon which the organ reposes.

These curious fibro-vesicular bodies resemble, in a striking manner, the fibro-cellular tissue which forms the parenchyma in the leaf of *Pleurothallis racemosa*.

I could not detect a cytoblast at either of their terminations, but a few of these organs were dispersed upon the membrane. The vessels with cæcoid appendages frequently passed over them, but in no determinate direction, and I could not detect any communication existing between them. The average size of the vesicles measured $\frac{1}{420}$ of an inch long, by $\frac{1}{2000}$ of an inch in diameter.

The results of the examination of the various species of Corallidæ which have furnished the subjects of this paper, are such as we might have expected after a careful perusal of the valuable papers of Mr. LISTER and Dr. ARTHUR FARRE, published in the Philosophical Transactions, 1834 and 1837. In the former, the author has displayed in an admirable manner the circulation of the fluids in the Tubulariæ and the Sertulariæ; while the latter, with an equal degree of talent, has rendered us familiar with the muscular organization and digestive processes of the ciliobrachiate polypi. From these researches it is but natural we should infer that an equal extent of organ-

ization exists in the nearly allied tribe of the Corallidæ, and that from the bases of the minute polyps, the chyliferous juices should be dispersed in every direction through the common mass of the stony body of the animal, and that the usual processes of the absorption and reproduction of parts should take place within their calcareous axes, as in the corresponding parts in the higher tribes of animals.

The structures which I have described are in other respects exceedingly interesting, as they establish a degree of organic connection between the Corallidæ and the Spongiadæ, which had not, I believe, before been suspected to exist, and at the same time have a tendency to confirm the idea of the animal nature of the latter. Whatever doubts may have existed at former periods in the minds of naturalists respecting the nature of the siliceous spicula of the sponge tribe, the fact of having found these curious organs so exactly similar in every respect amid the undoubted animal secretions of the Corallidæ, will stamp them as true animal productions. The vascular tissue with cæcoid appendages has a striking resemblance to that which I have described in Part I. vol. i. of the Transactions of the Microscopical Society, as found upon the fibres of one of the species of the sponges of commerce; and in the fleshy portions of *Tethea lyncurium* and *Geodia Zetlandica*, Lamarck, we find fleshy membranes, with minute vessels meandering through their substance in every direction, so closely resembling those obtained from the coral tribe, as to establish a degree of affinity between the Corallidæ and Spongiadæ so intimate as to appear to place the animal nature of the latter beyond a reasonable doubt. These tissues are in a like manner common to Nullipora. How far this may be the case with other apolypous corals remains yet to be proved; but should the same structures prevail in these as in that genus, it would go far to prove these curious bodies to be animals, instead of being, as heretofore considered, vegetables secreting calcareous matter in unusual quantities.

The cellular tissue of the Nulliporidæ is certainly, as regards both sponges and corals, anomalous, but the membranous and vascular tissues which accompany it are in an equal degree contrary to the types of the corresponding organs in any established vegetable body with which I am acquainted. Their true position in the scale of organization would therefore seem to be between the Corallidæ and Spongiadæ; abounding in membranous and vascular tissues, like those of the former, but totally destitute of polypiferous organisms, like the latter; while the cells and their accompanying cytoblasts are but a more methodical development of the same laws that we observed in operation in the membranous portions of almost every coral that was examined.

Explanation of the Plates.

PLATE XVI.

Fig. 1. Vascular tissue with cæcoid appendages. *Millepora alcicornis.*

Fig. 2. Large vascular tissue with valves *a a* at the entrance to the vessels with cæcoid appendages, and at *b*, upon the main trunk of the vessel. *Millepora alcicornis.*

Figs. 3, 4. Large vascular tissue with valves, from *Cellepora pumicosa.*

Fig. 5. Branched and cellulated vascular tissue, from *Pavonia Boletiformis.*

Fig. 6. The same tissue with ovoid bodies at the apex.

Fig. 7. Large brown, round or oval bodies, with moniliform vessels, from *Pavonia Boletiformis.*

Fig. 8. Siliceous spicula and cytoblasts imbedded in the membranous tissue of Anthopora.

PLATE XVII.

Fig. 1. Strings and groups of cytoblasts from *Millepora alcicornis.*

Fig. 2. Vessel continued by cytoblasts from *Millepora alcicornis.*

Fig. 3. Membranous sacs with cytoblasts at their apices, and minute vascular tissue with cæcoid branches terminated by cytoblasts. *Cellepora pumicosa.*

Fig. 4. One of the membranous sacs of the same, magnified 800 linear.

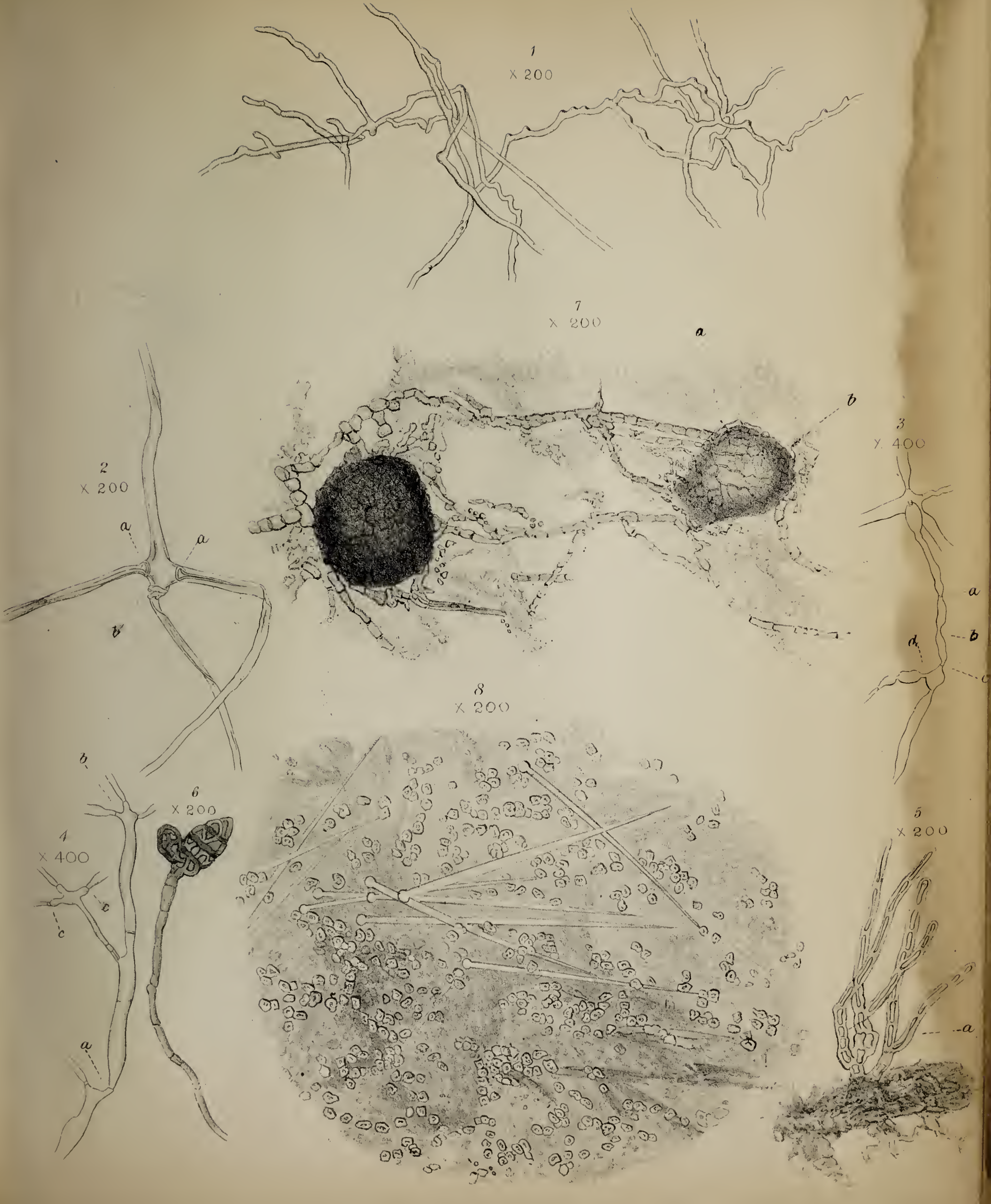
Fig. 5. Cellular structure in a Nullipora from Sydney, Australia, exhibiting the ends of the cells with the cytoblasts at the apices.

Fig. 6. A lateral view of the same tissue, with the cells empty.

Fig. 7. A single cell uncompressed, from the same, with the cytoblast at the apex.

Fig. 8. Fibro-vesicular tissue from a species of Agaricia, nearly allied to *A. ampliata.*

Fig. 9. Two cytoblasts from Anthopora, magnified 800 linear.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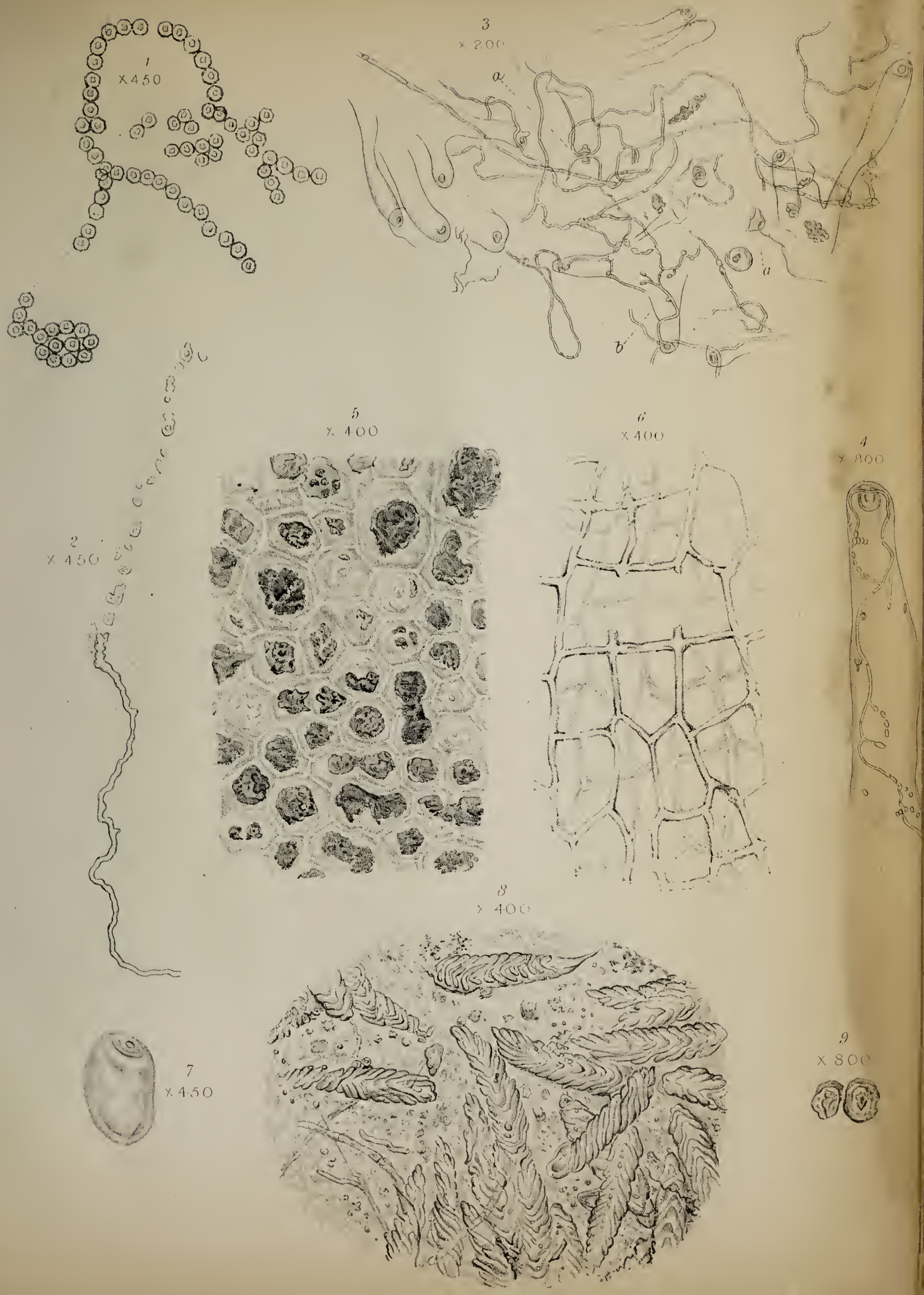

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2
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3
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×800
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6
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7
×450
8
×400
9
×800

XIV. THE BAKERIAN LECTURE.—*On the Transparency of the Atmosphere and the Law of Extinction of the Solar Rays in passing through it. By* JAMES D. FORBES, *Esq., F.R.S., Sec. R.S. Ed., Corresponding Member of the Royal Institute of France, and Professor of Natural Philosophy in the University of Edinburgh.*

Received May 20,—Read May 26, 1842.

CONTENTS. § I. *Qualities of Rays.* § II. *History of the Inquiry.* § III. *On the Mass of Atmospheric Air traversed by Rays with varying obliquities.* § IV. *Account of the following Observations:—Comparison of Actinometers—Reduction to Intervals of One Minute.* § V. *Analysis of the Observations of the* 25*th of September*, 1832. § VI. *Concerning the Law of Extinction.* § VII. *Other Observations in* 1832. § VIII. *Observations in* 1841. § IX. *Conclusions.*

1. THE experiments which will chiefly be analysed in this paper were made nearly ten years since. I have been deterred from drawing the conclusions from them which they warrant, partly by the great labour of the necessary reductions, and partly by peculiar and inherent difficulties which this intricate subject presents. For the computations I am much indebted to the perseverance and care of Mr. JOHN BROUN (now magnetical assistant to Sir THOMAS BRISBANE), who has made most of them under my eye, and also to Mr. JAMES STARK. For much which yet remains obscure and uncertain in my conclusions, I anticipate the indulgence of those best acquainted with the uncertainties under which the subject of absorption, whether of light or heat, is still veiled, and with the little advance which has been made in the particular branch which we have to consider, namely the law of extinction of solar light and heat in the atmosphere.

2. Permanently enclosed as we are within an imperfectly transparent shell which separates us from the realms of space, a knowledge of the various properties of the atmosphere, especially as regards light and heat, is peculiarly important in the resolution of many cosmical problems. We cannot at will place ourselves, as it were, in a point in space, until we can eliminate the effects of this transmission. Hence the great importance of the subject of astronomical refractions, one nearly allied to the present, and which has exercised, from the time of NEWTON to that of IVORY, the happiest skill of some of the most eminent analysts and natural philosophers. The difficulties of the doctrine of astronomical refractions it has in common with that of the extinction of light, and to these are superadded many more, owing to the incomparably inferior methods which we have of measuring both light and heat compared to the measure of angular quantities.

Section I.—*Qualities of Rays.*

3. Not to incur a charge of vagueness, to which our remarks may be thought liable when we speak of light and heat together, I would first notice the difficulty under which we labour in this respect. Our instruments are so imperfect that it is difficult to say what particular effect we are truly measuring at a given time. The solar rays contain light and heat; and each of these results of radiations varies, first, in respect of intensity, and secondly, in respect of quality. We may *seem* to perceive a change in the first of these effects when it is only the second which has varied. Light may be more or less brilliant, but it may also be red or yellow. Heat may be more or less intense, but it also changes its quality in a manner similar to the effect of coloration for light. A person who could distinguish only yellow rays of light, would feel as if plunged in darkness when the red ray of the spectrum was directed on his eye. Our instruments for the measurement of heat possess undoubtedly something like the quality now supposed to exist in a natural eye. They may indicate, not the whole intensity of the incident heat, but only the intensity of that modification of it, to which the measurer applied is exclusively or peculiarly sensitive. As we employ a black, or a blue, or a white thermometer to measure the force of the solar rays, we shall have indications not only *absolutely* different, but *relatively* different under different circumstances. Interpose, for instance, a plate of glass, and though the same reduced quantity of heat falls upon all the three instruments, the black thermometer will sink less than the white one would do*. We cannot tell but that the atmosphere acts as the plate of glass does, and therefore, that the indication of the opacity of the atmosphere in respect to the heating rays is only true as regards a certain class of heating rays: nay, it is almost demonstrated that such is the case; and that consequently we must use "law of extinction," "transparency of the atmosphere," and such terms, with especial and exclusive reference to the class of effects which our instrument is capable of measuring.

4. The direct quantitative measurement of light has not yet been satisfactorily accomplished; and of the indirect methods, some depend upon the faculty of the eye in comparing illuminated surfaces, and others upon the thermometric effects which the luminous calorific rays produce. We can by no means conclude that these two methods, so dissimilar, of estimating the loss of solar light in its transit through the atmosphere, ought to give identical results. The one was practised by Bouguer, the other by Lambert; and it is to the latter class alone that the experiments to be described in this paper belong: but before detailing them, it may be well to glance historically at the more important parts of the problem.

Section II.—*History of the Inquiry.*

5. Sir Isaac Newton, in the third book of his Optics, speaks of the opacity or imperfect transparency of bodies as arising from the multiplied reflections of light

* Powell, Philosophical Transactions, 1825.

in their interior, owing to a want of perfect homogeneity; but he does not seem to have pushed the consideration of the matter much further, at least so far as I recollect of the history of optics of his time. It is to BOUGUER that we owe the first careful consideration of the varying intensities of absorbed and reflected light, and a special application of it to the case before us, the transparency of the atmosphere. Father FRANÇOIS MARIE had, indeed, in 1700, described an instrument intended to measure the intensity of light, but he failed grievously in his proposed application of it*. It consisted of a series of plates of glass, or increasing thicknesses of water, to be interposed between the eye and the object until the light should be wholly stopped. But the writer proceeded on the inaccurate idea, that each successive plate, or increment of thickness, would stop an equal proportion of the *original* light instead of an equal share of the light *incident* upon it. The former, being an arithmetical progression, would produce a speedy and complete extinction; the latter would give a continually diminishing geometrical proportion, which would approach slowly and indefinitely to zero.

6. This last analogy BOUGUER perceived and proved in a tract published in 1729, which was only the precursor to his great work, published after his death, under the title of "Traité d'Optique sur la Gradation de la Lumière"†. He shows that, from the geometrical law of extinction just alluded to, the remaining intensity of light, after having passed through any thickness of a *uniformly dim* medium, may be represented by the ordinates of a logarithmic curve, the abscissæ denoting the thickness. This property he ingeniously applies with considerable mathematical skill to a variety of cases. The chief of these is to the transparency of the atmosphere.

7. MAIRAN had already shown‡ that the varying thickness of the atmosphere, traversed by rays from the heavenly bodies at different altitudes, during their diurnal course, produces a continual variation in their apparent brightness; and he anticipated the possibility of deducing the total loss in *one* transit by comparing the losses due to different thicknesses. But he was ignorant of the logarithmic law discovered by BOUGUER; for he supposed the losses of light proportional to the lengths of the paths traversed§. The latter gave the theoretical solution of the problem, and applied it to practice. It being inferred from what has been already stated, that the intensities are in a geometrical progression when the thicknesses vary arithmetically, it follows that the thickness traversed, of a homogeneous medium, is proportional to the difference of the logarithms of the incident and transmitted light, or what comes to the same thing, it is proportional to the logarithm of their ratio. Thus, if for atmospheric thicknesses x_1 and x_2, the transmitted light be v_1 and v_2; also, if V be the intensity of light exterior to the atmosphere, and m a constant

$$\log \frac{V}{v_1} = m x_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1.)$$

* Nouvelle Découverte sur la Lumière pour en mesurer et compter les degrés. Cited in MONTUCLA, Histoire des Mathématiques, iii. 538, where there is a good sketch of the history of photometry.

† 4to, Paris, 1760. ‡ Mémoires de l'Academie, 1721. § Mém. p. 14.

$$\log \frac{V}{v_2} = m\, x_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2.)$$

Subtracting

$$\log \frac{v_2}{v_1} = m\,(x_1 - x_2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3.)$$

where everything is known except m, which is thus determined, and which substituted in eq. (1) gives the value of V the unknown intensity exterior to the atmosphere in terms of the same unit as v_1 and v_2. For eq. (1) may be written

$$\log V - \log v_1 = m\, x_1$$

and

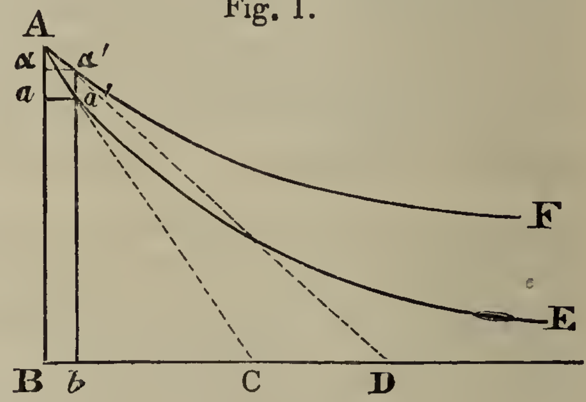
$$\log V = \log v_1 + m\, x_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4.)$$

8. This was the principle of BOUGUER's solution; the values of v_1 and v_2 were determined by comparing the intensity of moonlight for different elevations. Thus at elevations of 19° 16′ and of 66° 11′ the intensities were as three to two when compared by means of the light of wax candles at variable distances*. The values of x_1 and x_2 were determined from the supposed constitution of the atmosphere in a manner we shall afterwards make known.

9. The conclusion at which BOUGUER on the whole arrived was, that the light of the sun and stars would, by a *simple vertical* transmission through the atmosphere, be reduced to 0·8123 of its original brightness†.

10. It is evident from the preceding investigation, that as the extinction of the ray depends on the rate of inclination of the logarithmic curve to its axis at any point, in different homogeneous substances, the intensity of the incident light being the same, the decreasing ratio of the light is inversely as the constant subtangent. Thus, let A B represent the light incident on a plate whose thickness is reckoned in the direction B D, and let A a be the decrement due to the passage of the ray through the thickness B b of any medium: let A α be the smaller decrement due to the action of a more transparent medium: then

Fig. 1.



$$A\,a : A\,B = B\,b : B\,C$$

and

$$A\,\alpha : A\,B = B\,b : B\,D,$$

whence

$$A\,a : A\,\alpha = B\,D : B\,C,$$

or the decrement is inversely as the subtangent of each curve.

* Four wax candles forty-one feet off equalled the intensity of moonlight with an elevation of 66° 11′, and the same number at a distance of fifty feet corresponded to an elevation of 19° 16′. The intensities are as the squares of the distances inversely, or as 2500 to 1681, or nearly as 3 : 2.

† Traité d'Optique, p. 332.

11. The definition of transparency, according to BOUGUER, is *the reciprocal of the thickness of the medium required to diminish the incident light in a given ratio.*

12. In the same year with the posthumous publication of BOUGUER, appeared the "Photometria" of LAMBERT; a work of great ingenuity and labour, based in many respects upon BOUGUER's earliest investigations already mentioned, to which the author fails not to give due credit. This work, owing to some circumstance, has always been very scarce: PRIESTLEY appears never to have been able to get a copy, and now it is one of the rarest of modern scientific works. It was printed under the title of "Photometria, sive de Mensura et Gradibus Luminis, Colorum, et Umbræ. Augustæ Vindelicorum, 1760, 8vo, pp. 547"*. In the first chapter of the fifth part, the author treats of the transparency of the atmosphere. His methods of finding the thickness of air traversed at different altitudes are less accurate approximations than that of BOUGUER. His method of observing the intensity of radiation was very different, as well as the result. He observed the degree at which a thermometer lying in the sun rose above one in the shade, and he took this difference as a measure of solar radiation. The experiments briefly cited in the "Photometria"† are fully detailed in his "Pyrometria," published in quarto in 1779‡. LAMBERT's observations on the intensity of the solar rays were made during a considerable part of the year. The following made at Coire on the 17th of May 1756, he selects as the best: the height of the barometer was twenty-six French inches.

Sun's Altitude.	REAUM. Excess in the Sun.
60°	15°·8
50	14·6
40	12·8
30	10·0.

Hence, by a procedure the same as has been above explained, he deduces the light transmitted through the atmosphere in a vertical direction, which he estimates at 0·5889 of the incident rays, being less than $\frac{3}{5}$ instead of more than $\frac{4}{5}$, as BOUGUER had supposed.

13. LAMBERT's work on Pyrometry is further remarkable for the clear description of several methods and results which have in later times been rediscovered or successfully applied. He was the first to apply calculation to the flow of heat through solid bodies§: he discovered the law of the intensity of radiant heat proportional to the sine of the angle made with the heated surface‖. He was aware that the true measure of the cause of radiant heat was the *velocity* of heating resulting from it¶. He applied this method to the determination of the permeability of successive plates of glass to the solar rays, constructing for each experiment the curve of rise of tem-

* The analysis of this work in Montucla is imperfect.
† page 396. § 886.
‡ page 158. § 283.
§ Pyr. § 327.
‖ Pyr. § 319.
¶ § 270.

perature in terms of the time elapsed, from which he deduced the velocity of heating under similar circumstances. The result of these experiments is remarkable as anticipating the law usually attributed to De la Roche, that the facility of transmission through successive plates of glass continually increases with the number already passed through*. He thus finds

		Loss.
Incident heat	100	
Through one plate of glass . . .	84	16
Through two plates of glass . .	69	15
Through three plates of glass . .	59	10.

We shall have occasion to return to this important experiment.

14. In 1774 De Saussure employed an instrument which he called a Heliothermometer, for measuring the force of the solar rays, particularly upon the top of mountains. It consisted of a wooden box lined with thick pieces of blackened cork, and covered with three separate superimposed glass plates which admitted the solar rays to a thermometer placed in contact with the cork: in this instrument the mercury rose to 70° Reaumur†.

15. Sir John Leslie, in his Essay on Heat‡, proposed a modification of his differential thermometer with one bulb blackened, and the other clear, as a photometer; since the excess of effect on the dark ball appearing only when heat is accompanied by light, might, he thought, be considered as a measure of the light. There is, however, a twofold objection to consider this instrument as exact in its indications. 1st. The quality of affecting dark surfaces more than pale ones, is a quality of heat often accompanying, but not inseparable from light. This has already been proved from Professor Powell's experiments, which have been further confirmed by M. Melloni, who finds, for instance, that a black and a white surface absorb lamp heat in the ratio of 100 to 80·5; and if the heat be transmitted through rock salt, the ratio is unchanged; but if alum be used instead of salt, though equally permeable to light, the ratio now becomes 100 : 42·9. But, secondly, an objection clearly foreseen by Lambert, is applicable to all measures of a radiant source by the *statical* effect on a thermometer. The condition of a body remaining at a higher temperature than the surrounding medium is this:—that it shall receive in a given time as much heat as it parts with: the more it receives the higher must be the temperature to which it must be raised in order to part (by the law of cooling) with an equal amount. The measure of intensity depending upon the stationary heat of the thermometer, clearly supposes that the cooling proceeds according to a constant law in all the experiments which are to be compared§.

* Pyrometrie, § 282. † Voyages dans les Alpes, § 932. ‡ 8vo, Lond. 1804.

§ The form which Lambert gave to his formula was this,—

$$d y = n d t - \frac{y d t}{S}$$

where y is the excess of temperature marked by the thermometer, n the heat communicated directly in unit of

16. The former of these objections applies to all thermometric instruments considered as *light* measurers; but the latter has been ingeniously got over by Sir JOHN HERSCHEL, in a way more convenient in practice than that used by LAMBERT.

17. HERSCHEL's actinometer consists of a thermometer with a large cylindric bulb, containing a deep-blue fluid (the ammonio-sulphate of copper), and inclosed in a wooden case, blackened interiorly and covered with a piece of thick plate glass. The capacity of the bulb may be caused to vary, by screwing in or out a plunger which enters parallel to the axis of the cylinder, and the use of which is to retain the top of the column of fluid within the range of the tube, which is connected with the cylinder as in the common thermometer, and which it would otherwise be liable to exceed, owing to the great variations of temperature to which it is exposed. The *velocity* of heating during exposure to the sun is ascertained by limiting the exposure to *one minute*, during which the rise of the liquid is accurately observed. But since during this minute, the rise was not that due to the solar influence alone, but to the direct solar influence *plus* or *minus* all the cooling or heating influences simultaneously acting on the actinometer, these indirect influences are ascertained and allowed for by exposing the instrument for *one minute* behind a screen, which merely stops the solar rays, but allows all other actions to go forward. If the instrumental readings *fall* during the shade observation (owing to the coolness of the atmosphere and the high temperature of the liquid), it is plain that the solar action was not only to *raise* but to *maintain* the temperature, and that the fall during the shade observation must be added to the rise during the sun observations to give the effect due to the sun. On the other hand, if the temperature continue to rise during the shade observation (which may be due to indirectly reflected heat, or to the communication of heat from the parts of the instrument), it is plain that the rise in the sun was not wholly due to the immediate solar influence, and therefore that the rise in the shade must be subtracted from it.

18. This instrument gives very constant and satisfactory results: it is the one with which the following observations were entirely made; examples of the mode of using it will therefore be given when I come to describe my own experiments. In the mean time I may refer for the first description of the actinometer to the Edinburgh Journal of Science for 1825*; and for a very full account of it, and the method of using it by Sir JOHN HERSCHEL himself, in the 'Instructions' lately published by the Royal Society†.

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time, *t* the time, and S the subtangent of the logarithmic curve which expresses the Newtonian law of cooling, having the excess of temperature above the medium for its ordinate, and the time for its abscissa. This subtangent varies (as he observes § 282) with the state of the atmosphere. It is very remarkable that LESLIE himself pointed out in his very earliest published composition (an Essay written in 1792 or 1793, but first printed in THOMSON's Annals of Philosophy in 1819, vol. xv. p. 7.), that "the *initial change*" (or rate of heating of a black surface exposed to the sun) "on the thermometer, is in every case *the only certain and accurate measure* of the communication of heat":—a principle which, however, he practically abandoned, as we have seen.

* Vol. iii. p. 107. † p. 58.

19. The scale of the actinometer is an arbitrary one obtained by the direct comparison of one instrument with another; a method which, as we shall see, admits of great accuracy. Sir John Herschel has, indeed, proposed to convert his degrees into "actines," each of which represents "that intensity of solar radiation, which at a vertical incidence, supposing it wholly absorbed, would suffice to melt one-millionth part of a metre in thickness from a sheet of ice horizontally exposed to its action, per minute of mean solar time*". It may be apprehended, however, that an arbitrary comparison will always be found more available in practice. The scale of Leslie's photometer should also be considered as arbitrary; the method of graduation by conversion into hygrometric degrees being wholly inaccurate.

20. Leslie, from his experiments made on the sun's force at different elevations, concluded that *one-fourth* of the solar rays are absorbed during a vertical transmission through the atmosphere in clear weather at Edinburgh†. His experiments were made under the revolving dome of an observatory‡. Thus the indirect heating and cooling influences were in some degree avoided. These influences are of a very material kind, and prove the impossibility of obtaining even an approximation to useful results without allowing for them. The photometer of Leslie indicates as much effect (according to Professor Kämtz) due to the light reflected from the atmosphere as to the direct solar influence; certainly a most startling result, but one entirely confirmed by my own observations. The part exclusively due to solar influence being taken by M. Kämtz, he finds from Bouguer's formula an extinction of no less than thirty per cent. of the solar rays in reaching the summit of the Faulhorn, by a vertical transit through the atmosphere, the pressure of which amounts there to only about twenty-one English inches§.

21. M. Pouillet, of Paris, described some years ago an apparatus for measuring solar radiation, in which the errors of other statical contrivances were in a great measure avoided, by enclosing the thermometer in an envelope maintained at 0° cent., with the exception of a small hole which exactly admitted the direct rays from the solar disk. Since that time he has adopted Herschel's dynamical method, which he has applied to a modification of the actinometer, which he terms a *pyrheliometer*; reserving (rather unfortunately, I think) the term actinometer, which was already so fitly appropriated, to a separate apparatus for measuring nocturnal radiation. These instruments and their applications are described in an ingenious and interesting memoir read to the Academy of Sciences, 9th July 1838, printed in the Comptes Rendus, and privately circulated under the title of "Mémoire sur la Chaleur Solaire sur les Pouvoirs Rayonnants et Absorbants de l' Air Atmosphérique, et sur la Température de l'Espace."

22. The pyrheliometer is composed of a thin metallic chamber containing water,

* Royal Society's Instructions, p. 65.

† Article 'Climate,' Encyclopædia Britannica.

‡ See my Supplementary Report on Meteorology in the British Association Report for 1840, p. 63.

§ Lehrbuch der Meteorologie, iii. 14.

blackened externally, and exposed to solar radiation, having a thermometer plunged into it, which ascertains the rate of heating or cooling of the fluid in the chamber. It is observed by sun and shade alternating series, after the manner invented by HERSCHEL, and the whole instrument is only a less perfect modification of the actinometer under a form slightly different. M. POUILLET, from observations at Paris, finds the absorption of solar heat to follow very rigorously the law of BOUGUER,—namely, that the mass of air traversed varies as the logarithm of the ratio of the intensity observed to the constant intensity beyond the atmosphere. He gives it the form*

$$t = A p^{\varepsilon};$$

where t is the observed intensity, A is what he calls the solar constant (*i. e.* the intensity beyond the atmosphere), p the atmospheric constant which determines the opacity, and ε the mass of air to be traversed.

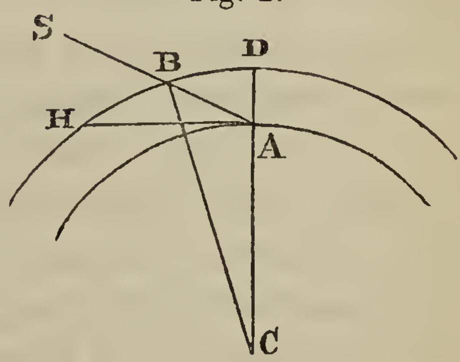
23. That this comes under BOUGUER'S form is easily seen by taking the logarithms of both sides:—

$$\log \frac{t}{A} = \varepsilon \log p,$$

where $\log p$ is a constant. From his various observations M. POUILLET concludes that the loss by vertical transmission is sometimes as low as eighteen per cent., and seldom higher than twenty-five per cent. when the sky appears pure.

SECTION III.—*On the Mass of Atmospheric Air traversed by rays with varying obliquities.*

Fig. 2.



24. It follows, from the simplest geometrical considerations, that if the strata of air be ranged concentrically, and if the thickness of the atmosphere A D be small compared to the radius of the globe C A, the length of path A B of the rays of light will vary nearly as the secant of the zenith distance, except near the horizon. It is, of course, supposed (which is the fact) that the curvature of the path A B is so inconsiderable as not materially to affect its length. Within the limits between which the above approximation may be accepted as correct (that is, for altitudes above 15° for most purposes), it is plain that the law of densities at different heights is left out of account; for the hypothesis amounts to considering the strata as *flat*, and therefore as all cut by the ray at the same angle.

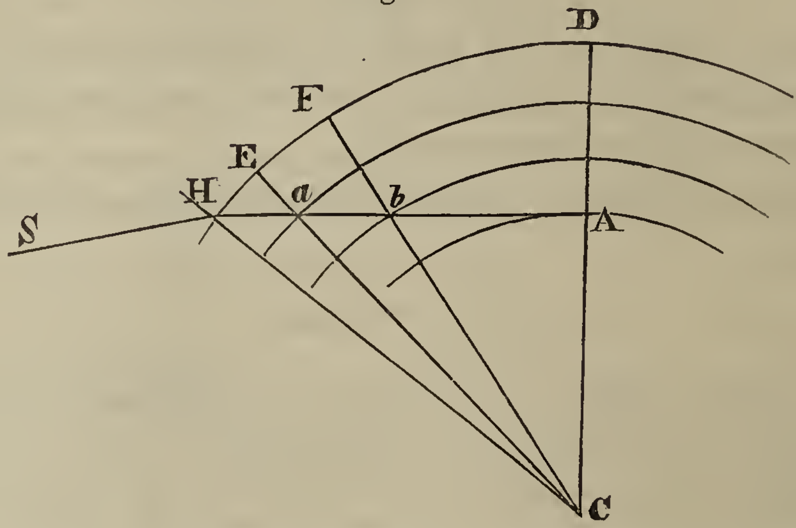
25. Near the horizon, however, this law can give no approximation, for there the secant would give an infinite thickness traversed, whilst the curvature of the globe and atmosphere limits the path to the length of the line A H. If we would, therefore, ascertain the length of path, we must ascertain the length of A H; and so

* Mémoire, p. 6.

for all low elevations. This infers a knowledge of the height of the atmosphere; but more than this, it requires that we should be able to ascertain the density of each particular stratum of air, for each stratum is traversed at a different obliquity, and the quantity of matter which each stratum opposes to the passage of the ray is evidently proportional to the density of the stratum, and the length of path in the stratum. The mass of air penetrated will be the integral of all such elementary parts.

26. Supposing the atmosphere divided into three strata of equal thickness but differing in density, it is evident that the horizontal ray H A will traverse the com-

Fig. 3.



paratively short space H a of the highest, the longer space a b of the middle stratum, and by far the longest course b A in the lowest (the curvature of the path being small). Now as the lowest stratum is also the densest, it follows that on both these accounts the stratum in which we are placed acts most energetically, and hence the thickness traversed by a horizontal ray may be represented by a highly converging series upon almost every physically-possible hypothesis of density.

27. This figure also shows that, supposing the strata numerous and thin, the thickness of each stratum traversed will be equal to its vertical thickness multiplied into the secant of the angle of incidence of the transmitted ray.

28. Lambert contented himself with finding in the first place in fig. 2. the length of the line A H or A B from simple geometrical considerations, which he gives in these terms*,

$$\cos\gamma + x = \sqrt{\cos^2\gamma + 2\,y + y^2};$$

where γ is the zenith distance, y is the height of the particular stratum D B H (the earth's radius being $= 1$), and x is the length of the path A B or A H. He then differentiates the expression in respect of x and y, and multiplying the element of the path thus found by the density of the stratum (variable with y according to some law to be assumed), he expands the quantity to be integrated in a series, of which, however, he has not attempted to find the exact value, but stops at the first term which is proportional to the secant of the zenith distance, as we have seen. The only person

* Photometria, p. 393.

who, so far as I know, has pushed the approximation *practically* to the second term, which has the form

$$B \tan^3 \gamma \,.\, \sec \gamma,$$

is Professor Kämtz*. M. Pouillet has simply adopted the first formula above given, which, as it supposes the density constant, will make the mass of air traversed appear too small, producing in his results an accidental compensation of errors to which we shall afterwards allude.

29. Lambert's approximations are entirely of a tentative kind, that is, deduced *à posteriori* by ascertaining from a number of observations corresponding to the number of unknown coefficients, the successive terms of a series or points of an interpolating curve.

30. This method is objectionable in this respect,—that it proceeds upon the assumption of the uniform opacity of equal successive masses of air, upon which alone the logarithmic form of the law of absorption is correct. Since our object ought to be to verify this law, we must have a direct method of ascertaining the mass of air traversed by a ray at different elevations, which can only be founded on an *approximate* knowledge of the constitution of the atmosphere.

31. Bouguer had previously solved the problem in a direct manner, though by approximation, which is indeed the only method it admits of. Assuming the logarithmic law of densities and heights in the atmosphere (as in the common barometric formula), and supposing the temperature constant, he obtained a converging series for the atmospheric mass traversed by a horizontal ray, and also at different elevations†. This he expressed in thicknesses of air of the common density at the earth's surface: assuming the height of the equiponderant column of a uniform atmosphere at 3911 toises, he finds the mass traversed at 45° of elevation to be 5530 toises, and at the horizon 138,823 toises. Notwithstanding that he says that the approximation was not pushed very far, we shall show presently that Bouguer's determination corresponds well with that obtained by the most recent methods.

32. Laplace has considered the subject of the extinction of light by the atmosphere in the third chapter of the tenth book of the *Mécanique Céleste*. He has there ingeniously established an analogy between the amount of astronomical refraction and the mass of air traversed by a ray in any direction. By this means, the ample knowledge which we at present possess respecting astronomical refractions becomes immediately applicable to the subject before us.

33. I may remark, however, in passing, that in inquiring into the law of the extinction of light by the atmosphere, we would do well to avoid much use of observations near the horizon, the opacity of the vapours in the atmosphere introducing a variable and important element not recognizable with any accuracy by common meteorological observations. Any law of extinction will, therefore, be better determined from multiplied observations at elevations above 15°, than by those nearer the horizon, which are liable to more than all the objections to astronomical observations made

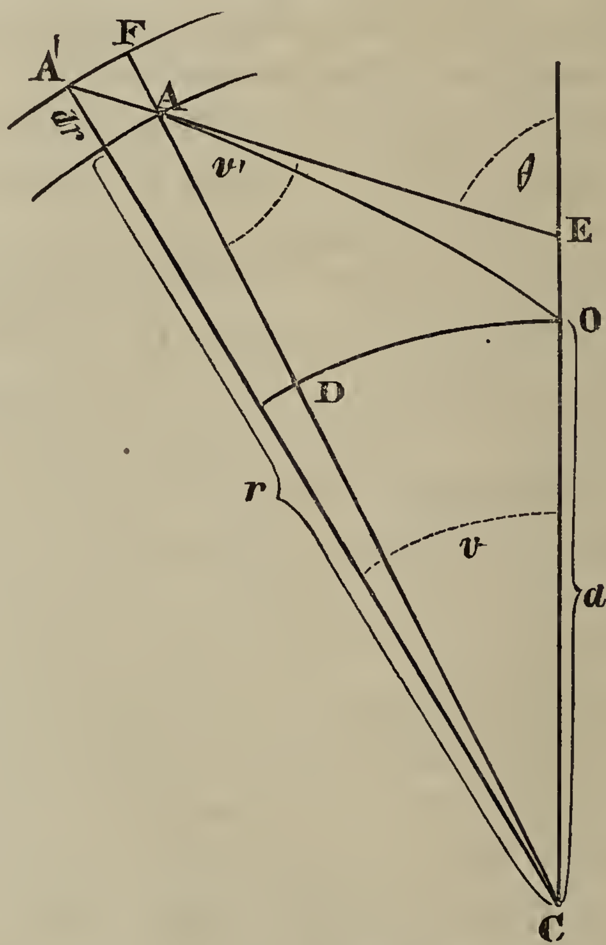
* Météorologie, III. 13.

† Traité d'Optique, p. 331.

under similar circumstances. For smaller zenith distances it has already been observed that LAMBERT's simple law of the secant gives an approximation quite within the limits of error of the observations to be compared. I have, therefore, adopted it uniformly in my reductions, partly for the sake of simplicity, partly on account of a doubt I at one time entertained respecting the admissibility of one of LAPLACE's approximations,—a doubt which was removed by consultation with my colleague, Professor KELLAND. I think it may be useful, however, to give a short proof of LAPLACE's method, on account of its accuracy and simplicity, in which everything belonging merely to the subject of refraction shall be omitted, and only what is essential to the law of extinction considered. In doing this I shall avail myself of the valuable assistance afforded by BOWDITCH's notes to his translation of the *Mécanique Céleste*.

34. i. *To find the differential equation of the Intensity of transmitted Light.*—Let O D. (fig. 4.) be a portion of the earth's surface, C its centre, A′ A O the path of a ray of

Fig. 4.



light; C A $= r$ the radius of any concentric stratum of the atmosphere, whose thickness A F $= d\,r$. Let the angle A′ A F $=$ E A C $= v'$, which denotes the angle with the radius made by the ray in passing through the stratum under consideration. Then the thickness of the stratum traversed will be A A′ $= d\,r \sec v'$; and if the density of the air in the stratum be ϱ, the mass of air passed through varies as $\varrho\, d\,r \sec v'$.

35. Let ε represent the intensity of the light just entering the stratum A′ F, then it will suffer a decrement $-\,d\varepsilon$ in passing through the stratum A′ A, bearing a constant proportion to the brightness of the incident beam and to the resistance which it has to encounter (supposing the opacity of a medium to depend solely on the number of

material particles which it contains, without reference to their distribution). Consequently

$$d\varepsilon = - Q . \varepsilon . \varrho \, dr . \sec v' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1.)$$

Q being a constant quantity.

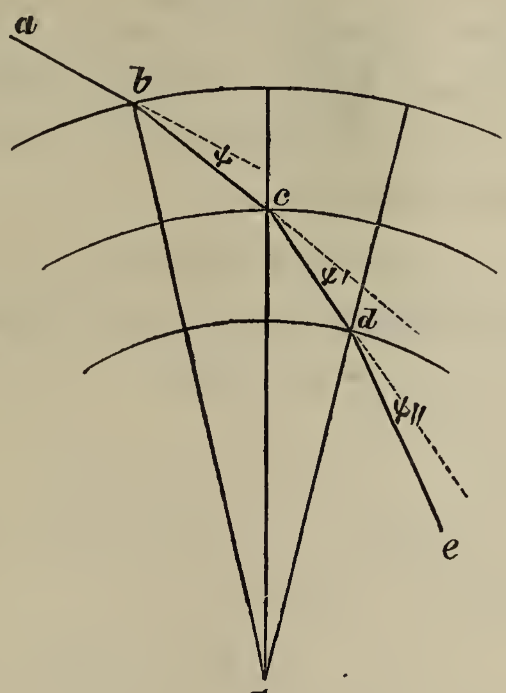
36. ii. *To find the differential of refraction.*—In fig. 4. θ is the angle formed with the zenith by any element A′ A of the path of a ray A′ A O refracted in the atmosphere. Hence the variation of θ or $d\theta$ is the differential of refraction. Now

$$\theta = v + v' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2.)$$

$$d\theta = dv + dv' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3.)$$

37. iii. When light is refracted at successive concentric surfaces of varying density, the flexure of the ray at each is the differential element of refraction. Thus in fig. 5. it is evident that the course of a ray being represented by the polygon *a b c d e*, the

Fig. 5.



flexure at the common surface of each successive stratum ψ, ψ', ψ'', &c., due to the inequality of the angles of incidence and refraction, measures the actual deviation of the ray from a rectilinear course*. Hence

$$\text{refraction} = \psi + \psi' + \psi'' + \text{\&c.},$$

and

$$\delta\theta = \psi \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4.)$$

38. iv. When light passes from one part of a medium whose density is ϱ, to another part of the same medium whose density is ϱ',

$$\text{sine incidence} : \text{sine refraction} = \sqrt{1 + k\varrho'} : \sqrt{1 + k\varrho},$$

k being the *refractive power* of the medium. This optical principle is derived from experience.

Let $\varrho' = \varrho + \delta\varrho$, then

$$\frac{\text{sin incidence}}{\text{sin refraction}} = \frac{\sqrt{1 + k\varrho + k\delta\varrho}}{\sqrt{1 + k\varrho}}.$$

* I specify this, because at first sight it would seem as if the flexure in question taking place round a normal, which is itself continually changing, would not express the due deviation.

39. v. Now let the ray of light be conceived to return in fig. 4. by the path O A A′, or in fig. 5. through $d\,c\,b$, then the angle of incidence is v' (fig. 4.) and the angle of refraction is (by fig. 5.) $v' + \psi$, or by eq. (4.) $v' + \delta\,\theta$. Hence

$$\frac{\text{sin incidence}}{\text{sin refraction}} = \frac{\sin v'}{\sin (v' + \delta\,\theta)} = \frac{\sqrt{1 + k\,\varrho + k\,\delta\,\varrho}}{\sqrt{1 + k\,\varrho}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5.)$$

$$\sin v' : \sin (v' + \delta\,\theta) = \sqrt{1 + k\,\varrho + k\,\delta\,\varrho} : \sqrt{1 + k\,\varrho}.$$

And passing to differentials,

$$\sin v' : \cos v'\, d\,\theta = \sqrt{1 + k\,\varrho} : -\tfrac{1}{2}\,\frac{k\,d\,\varrho}{\sqrt{1 + k\,\varrho}},$$

$$\frac{\cos v'}{\sin v'}\, d\,\theta = -\,\frac{k\,d\,\varrho}{2\,(1 + k\,\varrho)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6.)$$

$$d\,\theta = -\,\frac{k\,d\,\varrho}{2\,(1 + k\,\varrho)}\,\tan v' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7.)$$

40. vi. Let us now compare equations (1.) and (7.), being the differential values of extinction and of refraction. We observe first, that on the hypothesis of a uniform temperature throughout the atmosphere, the logarithmic law which connects density with height gives us the relation

$$-\,d\,\varrho : \varrho = d\,r : l,$$

the logarithmic subtangent or height of the equiponderant column. Hence

$$\varrho\,d\,r = -\,l\,d\,\varrho \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8.)$$

Substituting, equation (1.) becomes

$$\frac{d\,\varepsilon}{\varepsilon} = d\,.\log\varepsilon = \mathrm{Q}\,l\,d\,\varrho\,\sec v' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9.)$$

Eq. (7.) gives for the element of refraction

$$d\,\theta = -\,\frac{k\,d\,\varrho}{2\,(1 + k\,\varrho)}\,\tan v'\,;$$

dividing this by the former,

$$\frac{d\,\theta}{d\,.\log\varepsilon} = -\,\frac{k}{2\,\mathrm{Q}\,l\,(1 + k\,\varrho)}\,\sin v' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10.)$$

41. vii. It remains to determine the value of $\sin v'$.

By eq. (3.) $\quad d\,v' = d\,\theta - d\,v \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11.)$

By fig. 4. $\quad \left.\begin{array}{l} \mathrm{A}'\,\mathrm{F} = r\,d\,v \\ \mathrm{A}'\,\mathrm{F} = d\,r\,.\,\tan v' \end{array}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12.)$

Equating the two last,

$$d\,v = \frac{d\,r}{r}\,\tan v' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13.)$$

Substituting in eq. (11.) from (7.) and (13.)

$$\frac{d\,v'}{\tan v'} = -\left\{\frac{k\,d\,\varrho}{2\,(1 + k\,\varrho)} + \frac{d\,r}{r}\right\},$$

$$\frac{-\cos v'\,d\,v'}{\sin v'} = \frac{d\,r}{r} + \frac{k\,d\,\varrho}{2\,(1 + k\,\varrho)}.$$

Integrating,

$$\log C - \log \sin v' = \log r + \log \sqrt{1 + k\varrho},$$

C being a constant,

$$\frac{C}{\sin v'} = r\sqrt{1 + k\varrho} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14.)$$

When the ray starts from O (fig. 4.) the angle at which it intersects the inferior stratum is the apparent zenith distance $= \Theta$; therefore $v' = \Theta$; let also $r = a$ the earth's radius, and $\varrho = (\varrho)$ the density at the earth's surface. Under these circumstances

$$\frac{C}{\sin \Theta} = a\sqrt{1 + k(\varrho)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15.)$$

Dividing by (14.)

$$\frac{\sin v'}{\sin \Theta} = \frac{a}{r} \cdot \frac{\sqrt{1 + k(\varrho)}}{\sqrt{1 + k\varrho}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16.)$$

42. viii. Substituting this value of $\sin v'$ in eq. (10.) it becomes

$$\frac{d\theta}{d \cdot \log \varepsilon} = \frac{-k}{2Ql} \cdot \frac{a}{r} \sqrt{\frac{1 + k(\varrho)}{(1 + k\varrho)^3}} \cdot \sin \Theta \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17.)$$

In which, if we consider $k(\varrho)$ and $k\varrho$ each as small compared to unity, and $\frac{a}{r}$ as nearly equal to unity, the coefficient of $\sin \Theta$ on the second side will be constant for any value of the zenith distance. Also these approximations will be as exact near the horizon as elsewhere. Hence eq. (17.) may be written*

$$d \cdot \log \varepsilon = -\frac{H \cdot d\theta}{\sin \Theta} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (18.)$$

Integrating and supplying the constant E, and calling now $\delta\theta$ the *whole* refraction,

$$\log \frac{E}{\varepsilon} = \frac{H\,\delta\theta}{\sin \Theta} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (19.)$$

Here E is the value of ε when refraction commences at the exterior limit of the atmosphere; it is therefore the measure of the intensity of solar light there†.

43. ix. From the expression (19.) we may deduce the intensity proper to any altitude from two observations, as by Bouguer's method.

Let Θ_1 Θ_2 be the apparent zenith distances;

$\delta\theta_1$ $\delta\theta_2$ the corresponding refractions;

ε_1 ε_2 the corresponding intensities of transmitted light observed.

By eq. (19.)

$$\log \frac{E}{\varepsilon_1} - \log \frac{E}{\varepsilon_2} = H \left\{ \frac{\delta\theta_1}{\sin \Theta_1} - \frac{\delta\theta_2}{\sin \Theta_2} \right\},$$

$\log \frac{E}{\varepsilon_1} - \log \frac{E}{\varepsilon_2} = \log \frac{\varepsilon_2}{\varepsilon_1}$ is known from observation. Let it $= R$:

* Méc. Cél., IV. 283.

† E and ε have the same meanings here as V and v in a former part of this paper. In the Mécanique Céleste E is supposed $= 1$, and that letter is used to denote what we have used $[\varepsilon]$ for, farther on.

hence

$$H = R \left\{ \frac{\delta \theta_1}{\sin \Theta_1} - \frac{\delta \theta_2}{\sin \Theta_2} \right\}^{-1} \quad \ldots\ldots\ldots \quad (20.)$$

Also by eq. (19.)

$$\log E = \log \varepsilon_1 + H \frac{\delta \theta_1}{\sin \Theta_1} \quad \ldots\ldots\ldots \quad (21.)$$

whence the intensity without the atmosphere becomes known.

For any other zenith distance Θ_n,

$$\log \varepsilon_n = \log E - H \frac{\delta \theta_n}{\sin \Theta_n} \quad \ldots\ldots\ldots \quad (22.)$$

44. x. This expression fails at the zenith; but for all considerable elevations above the horizon the thicknesses of air traversed are as the secants of the zenith distances, and consequently the logarithm of the loss of light is in the same proportion. (See eq. (1.) p. 227). If $[\varepsilon]$ represent the intensity after a vertical transmission, and ε_1 that at an elevation of 45°,

$$\log \frac{E}{[\varepsilon]} : \log \frac{E}{\varepsilon_1} = 1 : \sec 45^\circ,$$

$$= 1 : \surd 2,$$

$$\log \frac{E}{[\varepsilon]} = \sqrt{\frac{1}{2}} \cdot \log \frac{E}{\varepsilon_1} \quad \ldots\ldots\ldots \quad (23.)$$

For instance, BOUGUER's result for a vertical transmission, $\frac{E}{[\varepsilon]}$ is ·8123. Substituting this in eq. (23.) the intensity at alt. 45° would be found; and for any other elevation the logarithm of the intensity compared to E would be found to be proportional to the refraction divided by the sine of the apparent zenith distance. From what has just been said, the atmospheric masses intercepted are in the same proportion as the logarithms of the intensities. Thus, let μ_1 and μ_2 be the masses of air traversed at 45° of elevation and at any other angle:

$$\mu_1 : \mu_2 = \frac{\delta \theta_1}{\sin 45^\circ} : \frac{\delta \theta_2}{\sin \Theta_2}.$$

Taking the value of the refraction from IVORY's latest Table*,

$$\mu_1 : \mu_2 = \frac{58''{\cdot}36}{\surd \frac{1}{2}} : \frac{\delta \theta_2}{\sin \Theta_2}.$$

For example, at the horizon, where $\delta \theta = 2072''$, the thickness at the zenith being unity, and therefore that at 45° $= \surd 2$,

$$\mu_2 = \frac{2072''}{58''{\cdot}36} = 35{\cdot}5034.$$

45. The other thicknesses are computed (always with reference to the perpendicular mass of the atmosphere) in the following Table: 1. by the approximate law of the secants; 2. by LAPLACE's analogy; 3. from BOUGUER's Table contained in his 'Optics,' which it will be seen scarcely differs from LAPLACE's result at the horizon. The first

* Philosophical Transactions, 1838.

column contains the zenith distance; the second, its secant; the third, the refraction by IVORY's Table; the fourth, the thickness by the formula $\frac{\delta \theta}{58''\cdot 36 \sin \Theta}$; the fifth, the corresponding mass of air in millimetres of mercury; the sixth, the thickness by BOUGUER's Table.

Table of Atmospheric Thicknesses corresponding to different Elevations.

$$\left[B = \frac{\text{Refraction}}{58''\cdot 36 \times \sin \text{Z. D.}}\right]$$

Z. D.	Sec. Z. D.	Refraction.	B.	B × 760mm.	BOUGUER's formula.
0° 0′	1·0000	0″·00	1·0000	760·0	1·0000
10	1·0154	10·30	1·0164	772·4	1·0153
20	1·0642	21·26	1·0651	809·5	1·0642
30	1·1547	33·72	1·1556	878·2	1·1547
40	1·3054	48·99	1·3060	992·5	1·3050
50	1·5557	69·52	1·5550	1181·7	1·5561
60	2·0000	100·85	1·9954	1516·4	1·9903
70	2·9238	159·16	2·9023	2205·8	2·8998
75	3·8637	214·70	3·8087	2894·7	3·8046
77 30	4·6202	257·74	4·5237	3438·0	
80	5·7588	320·19	5·5711	4234·0	5·5600
82 30	7·6613	418·59	7·2343	5498·1	
85	11·4737	593·96	10·2165	7762·7	10·2002
86	14·3356	707·43	12·1512	9234·9	12·1401
87	19·1073	866·76	14·8723	11303·0	14·8765
88	28·6537	1101·35	18·8825	14350·7	19·0307
89	57·2987	1466·8	25·1374	19104·4	25·8067
90	infinite	2072·	35·5034	26982·4	35·4955

SECTION IV.—*Account of the following Observations.*

46. In 1832 Sir JOHN HERSCHEL was good enough to direct my attention to the important use which might be made of his actinometers, to find the loss of solar radiation by simultaneous observations at the top and bottom of a mountain; and furnished with two instruments marked G. 7 and B. 2, which had formerly been used by Captain FOSTER in the arctic regions, I made very numerous observations in Switzerland and elsewhere that summer*.

47. We have already seen that, upon certain postulates (such as the uniform opacity of the air), the diminution of the effect of solar radiation in passing through the atmosphere may be ascertained by observations at any station, at varying altitudes. But it is certainly very interesting to test and confirm this indirect result by *simultaneous* observations at different heights in the atmosphere. By this means too, the influence of the meteorological conditions of a column of air directly under experimentmay be immediately ascertained. Balloon observations would theoretically be the most satisfactory, but they appear to offer practical difficulties, in this case nearly insuperable. Simultaneous observations at the top and bottom of a high insulated mountain were

* See Note A. at the end of this paper on the Scale of the Actinometers.

therefore indicated by Sir JOHN HERSCHEL as the most proper for "ascertaining the *very important point* of the comparative force of solar radiation at great and small elevations in the atmosphere*."

48. The difficulties in the way of such an attempt are greater than would at first sight appear, and probably will ever render *satisfactory* observations of this kind very rare. Two practised and zealous observers must agree to devote a considerable time to the experiment; for the assurance of fine weather to a degree that is very seldom met with in mountainous regions, is the first essential. The selection of a station elevated and insulated, and affording a *permanent* shelter to await the opportunity of making the observation, and of making experiments continuously when it arrives, is of the highest importance. At great heights on insulated mountains such stations are exceedingly rare indeed. The instruments employed must be rigorously compared, and the indications afterwards very carefully reduced. All these essentials were in a good measure united in the summer of 1832, and it will appear that I have not exaggerated the difficulties when I state that, among observations made at intervals for some weeks, those of one day only seem sufficiently perfect to yield consistent and trustworthy results†. Considering the value of that day's observations, I have spared no pains in analyzing them as completely as possible, both for the sake of the conclusions they afford, and also to point out for the encouragement of future observers, how well really good observations repay the labour of a detailed reduction. In meteorology, the making of observations is usually by far the least considerable part of the philosopher's task.

49. I was fortunate enough, not only to be provided with instruments and full instructions by Sir JOHN HERSCHEL, but likewise to make the acquaintance of a most zealous and able coadjutor, Professor KÄMTZ of Halle, who was about to proceed from Geneva (where we accidentally met) to an elevated insulated summit in the Oberland of Berne, called the Faulhorn, for the purpose of prosecuting meteorological observations for some weeks. I explained my objects of investigation, and he generously offered his best assistance, and soon acquired a knowledge of the instrument and its use. The month of September was the one he had selected. The Faulhorn is a hill or mountain, which lies exactly between the valley of Grindelwald and the Lake of Brientz. It is perfectly insulated, and commanding fine views in all directions, it has been found worth while to erect a small inn upon the summit, inhabited during a short part of the summer, where travellers can be accommodated. Its height above the sea is 8747 English feet‡. The barometer stands at $21\frac{1}{2}$ English inches: consequently nearly one-third of the atmosphere was left below. The comparative observations were chiefly made at Brientz, on the lake of that name, which has an elevation of only 1903 English feet§, consequently 6844 feet below the Faulhorn: and the difference of barometers (which had been compared and found accurately to

* Private letter of 5th August 1832.

† See Note B. at the end of this paper.

‡ HOFFMAN in BRUGIERE's Orographie; = 2666 metres.

§ Tralles.

agree) was six inches and seven lines French, or above seven English inches, being nearly one-fourth of the whole weight of the atmosphere. It was to be expected then, that if the opacity of the atmosphere for the heating rays at all approached the estimate of LAMBERT, the difference would be very sensible indeed, especially when in consequence of the rays passing through the interposed stratum of 6800 feet with a considerable obliquity, the resistance to their passage was magnified.

50. The month of September was rather changeable, and a fall of snow occurred about the middle of it, which affected so unfavourably the state of the atmosphere, that, though apparently clear weather followed, the results deducible from the observations were of the most anomalous kind. All the observations which the weather enabled us simultaneously to make at the top of the Faulhorn and at Brientz, Grindelwald, or other places in the neighbouring valleys, have been carefully and exactly reduced and computed; but it was not till near the close of the month that the atmosphere appeared to settle into a pure and steady autumnal condition. The 24th, 25th and 26th were brilliant and, so far as I observed, perfectly cloudless days. The 24th I spent partly with M. KÄMTZ on the Faulhorn. In the course of the 25th the observations were continued from the morning till sunset by M. KÄMTZ on the Faulhorn, and by myself at Brientz. To this series of comparative results the chief attention will be drawn. Those on the Faulhorn were made entirely in the open air, those at Brientz, until one o'clock inclusive, were made in a room, and afterwards in the open air, a discrepancy not altogether favourable to the series. At every hour the state of the atmosphere was ascertained by the barometer, thermometer, and moistened bulb hygrometer at both stations, thus giving as accurate a knowledge as the circumstances permitted, of the state of the intercepted column.

51. It is evident that these observations, immediately to be detailed, may be treated in *three* ways entirely distinct. The opacity of the atmosphere may be deduced from observations at different hours at the *upper* station only, by BOUGUER's formula founded on the logarithmic law of the decrement of solar intensity; the observations at the *lower* station give independent data; and finally, the direct determination of the loss of solar heat in passing from the upper to the lower station, by a comparison of the two instruments, yields a distinct result exclusively derived from the action of the lower strata of the atmosphere in absorbing solar heat. For this last purpose then a rigorous comparison of the arbitrary scale of the two instruments is of the highest importance. The following ample series of experiments will show the degree of accuracy attainable in such observations.

Comparison of Actinometers.

52. The comparison of the arbitrary scales of the two actinometers marked B. 2. and G. 7, was obtained by making alternating sets of observations on the solar intensity with each. It has already been stated that the method of using the instrument is to expose it to the sun for a certain short time (say one minute), then to interpose a

screen between the sun and the actinometer, and observe the effect of all other influences besides solar radiation for an equal space of time; and so on alternately subtracting algebraically the shade-effect from the sun-effect, so as to get the total influence of the solar rays. An example will make this clearer.

Paris.—M. Arago's Magnetic Cabinet, June 10, 1833.

Actinometer.	Hour.	Sun or shade.	Reading.	Diff.	Mean shade effect.	Sun-effect *minus* shade-effect.
B. 2.	h m s 12 26 0 27 0	shade.	18·3 10·9	– 7·4		
	27 0 28 0	⊙	10·9 40·2	29·3	–6·7	36·0
	28 0 29 0	shade.	40·2 34·2	– 6·0		
	29 0 30 0	⊙	34·2 64·3	30·1	–6·3	36·4
	30 0 31 0	shade.	64·3 57·7	– 6·6		
G. 7.	32 0 33 0	shade.	11·6 4·4	– 7·2		
	33 0 34 0	⊙	4·4 28·8	24·4	–6·85	31·25
	34 0 35 0	shade.	28·8 22·3	– 6·5		
	35 0 36 0	⊙	22·3 46·6	24·3	–6·45	30·75
	36 0 37 0	shade.	46·6 40·2	– 6·4		
B. 2.	38 0 39 0	shade.	33·7 23·5	–10·2		
	39 0 40 0	⊙	23·5 50·7	27·2	–9·3	36·5
	40 0 41 0	shade.	50·7 42·3	– 8·4		
	41 0 42 0	⊙	42·3 70·7	28·4	–8·55	36·95
	42 0 43 15	shade.	70·7 59·8	– 8·7*		

53. The following are the results of various series of observations similarly conducted.

* Reduced to 1^{m} interval.

I. Geneva, August 18, 1832.

			Ratio. B. 2. : G. 7.
Actinometer B. 2.	26·3		
G. 7.	22·4	26·3	1·174
B. 2.	26·3		
G. 7.	23·8	26·55	1·116
B. 2.	26·8		
G. 2.	23·9	26·8	1·121
		Mean	1·137

II. Geneva, September 5, 1832.

		Mean.	
B. 2.	18·0		
G. 7.	16·5	19·8	1·200
B. 2.	21·6		
G. 7.	19·9	21·9	1·100
B. 2.	22·2		
G. 7.	23·2	23·2	1·000
B. 2.	24·8		
G. 7.	20·0	22·5	1·125
B. 2.	20·8		
G. 7.	21·9	22·2	1·014
B. 2.	23·7		
		Mean	1·088

The differences here are evidently due to variations in the state of the atmosphere.

III. Faulhorn, September 24, 1832 (by M. Kämtz).

B. 2.	23·0 ; 22·7 ; 24·1	Mean 23·26		
G. 7.	17·2 ; 17·1 ; 17·7	Mean 17·33	24·14	1·393
B. 2.	23·8 ; 25·7 ; 25·6	Mean 25·03		
G. 7.	20·9 ; 21·3 ; 21·1 ; 22·2	Mean 21·37	26·3	1·231
B. 2.	27·3 ; 27·4 ; 27·8 ; 27·8	Mean 27·57		
			Mean	1·312

IV. Faulhorn, September 24 (Kämtz).

G. 7.	21·7 ; 24·2 ; 24·9 ; 24·9	Mean 23·92		
B. 2.	27·2 ; 28·8 ; 29·1 ; 29·1	Mean 28·55	25·04	1·140
G. 7.	25·4 ; 26·1 ; 27·0	Mean 26·16		

V. Paris, June 10, 1833. In M. Arago's Magnetic Cabinet.

G. 7.	29·9 ; 28·8	Mean 29·35		
B. 2.	35·8 ; 35·2	Mean 35·5	30·02	1·182
G. 7.	30·2 ; 31·2	Mean 30·7		
B. 2.	36·0 ; 36·4	Mean 36·2	30·82	1·174
G. 7.	31·2 ; 30·7	Mean 30·95		
B. 2.	36·5 ; 36·9	Mean 36·7	31·1	1·180
G. 7.	31·3 ; 31·2	Mean 31·25		
B. 2.	36·6 ; 35·1	Mean 35·85	30·92	1·159
G. 7.	30·8 ; 30·6	Mean 30·7		
B. 2.	34·4 ; 35·1	Mean 34·75	30·32	1·146
G. 7.	28·5 ; 31·4	Mean 29·95		
B. 2.	34·8 ; 35·5	Mean 35·15	30·15	1·166
G. 7.	30·6 ; 30·1	Mean 30·35		
			Mean	1·168

54. The mean of the whole, giving to each series its proper weight, is 1·154; but considering the variations of the second, third, and fourth series, and the extremely favourable circumstances and good agreement of the fifth, I prefer to adopt *it* alone, and assume for the factor of reduction G. 7. to B. 2. 1·168*.

Reduction to Intervals of One Minute.

55. In the instructions which Sir J. HERSCHEL had provided for me, it was observed that the velocity of heating or cooling might be noted for thirty seconds instead of one minute, and reduced to the standard unit by doubling it. But this does not appear to be exact, and in order to compare observations made with thirty-second intervals with those made at sixty-second intervals, a greater factor than 2 appears to be necessary, for reasons not difficult to anticipate. Whilst therefore I agree with the later instructions in preferring sixty-second intervals, it is useful to have a factor for reduction†.

56. Professor KÄMTZ, by careful and multiplied observations on the actinometer B. 2. at the Faulhorn, found the rise in 15, 30, and 60 seconds, to be proportionally 1, 2·345, 5·208 in the MS. notes with which he supplied me, and which almost exactly coincides with what he has stated in his work on Meteorology, vol. iii. p. 21. Hence the factor of reduction of thirty-second to sixty-second intervals is $\frac{5{\cdot}208}{2{\cdot}345} = 2{\cdot}224$, which I have employed when necessary.

57. The following Tables contain the meteorological observations on the 25th of September 1832, at Brientz and the Faulhorn, with the reductions necessary to render the results immediately applicable.

58. The observed times were nearly mean time at the place. They are reduced to *apparent time*, which is used in all the calculations and projections in which the actinometer is employed, on account of the facility which it affords for the direct comparison of observations at equal altitudes before and after noon.

59. The barometers used were both on the syphon construction: that at the lower station was divided on the old Swiss plan of French inches, lines, and 16ths with double readings. The upper barometer was divided into French lines and decimals, and was reduced to zero, REAUMUR, by M. KÄMTZ, before communicating the readings to me. I have reduced the other to the same temperature by means of its attached thermometer. Both barometers have been reduced into millimetres, which has been assumed as the standard of calculation (and 760 millimetres as the mean atmospheric pressure) for reasons which I need not now specify. The barometers were compared on the 24th of September and found to agree. Their index errors, as

* The observations at Geneva (first series), which are the best of the others, show that there is no reason for believing that the instruments had changed in any way at the date of the fourth series.

† Where by accident a single observation has been extended to seventy or seventy-five seconds, a simple proportional reduction will be sufficient, as shown in one of the examples already quoted.

well as those of the thermometers (which are all by good makers), are not recorded, but can hardly have an appreciable influence on any of the results about to be deduced.

60. The detached and moistened thermometers are reduced to FAHRENHEIT's scale, and the absolute elasticity of vapour in inches of mercury, as well as its hygrometric state relative to absolute saturation, are calculated from Dr. APJOHN's formula and tables*. The formula is

$$e'' = e' - \frac{1}{87}(t - t')\frac{b}{30},$$

where t and t' are the readings (FAHRENHEIT) of the dry and wetted thermometer; e' the maximum elasticity of vapours corresponding to t'; e'' that corresponding to the dew-point; b the observed height of the barometer in English inches†. The hygrometric observations have considerable interest in themselves owing to the extraordinary dryness of the air at the upper station,—a dryness, it is believed, altogether unusual even at that elevation; being an elasticity of vapour at $7\frac{1}{2}^{h}$ A.M. of only ·038 inch at temperature 39°, or ratio to saturation of ·148. This dryness must be considered as one of the peculiarly favourable circumstances of the present experiment.

TABLE A.—Meteorological Observations at Brientz, September 25, 1832.

Mean time.	Apparent time.	Barometer, French.		Attached Therm. REAUM.	Barometer in millimetres.	Attached Therm. Cent.	Barometer at 0° C. mm.	Detached Therm. FAHR.	Moist Therm. FAHR.	Diff.	Elasticity of vapour in inches of mercury.	Relative dampness.
h m	h m	inches.	lines 16ths.	°				°	°	°		
8 2	8 10	26	10·8	14·6	727·51	18·25	725·06	55·0	51·8	3·2	·362	$\frac{362}{442}$ = ·819
9 5	9 13	26	10·8	14·7	727·51	18·38	725·07	58·1	54·7	3·4	·401	$\frac{401}{491}$ = ·817
10 5	10 13	26	10·8	15·0	727·51	18·75	724·99	60·5	55·5	5·0	·395	$\frac{395}{532}$ = ·743
11 3	11 11	26	10·4	15·3	726·94	19·13	724·38	61·2	56·5	4·7	·414	$\frac{414}{545}$ = ·760
11 50	11 58	26	9·13	15·0	725·94	18·75	723·43	65·5	57·2	8·3	·386	$\frac{386}{628}$ = ·615
1 1	1 9	26	9·14	15·0	726·10	18·75	723·59	68·0	59·0	9·0	·408	$\frac{408}{681}$ = ·599
2 17	2 25	26	9·12	15·5	725·81	19·38	723·21	68·4	59·5	8·9	·418	$\frac{418}{690}$ = ·606
3 2	3 10	26	9·11	15·3	725·67	19·13	723·11	64·3	59·5	4·8	·460	$\frac{460}{603}$ = ·763
4 4	4 12	26	9·9	14·9	725·38	18·63	722·89	64·2	57·5	6·7	·408	$\frac{408}{601}$ = ·679
4 38	4 46	26	9·8	14·9	725·25	18·63	722·76	62·2	58·8	3·4	·466	$\frac{466}{563}$ = ·828

* In order to obtain tolerably consecutive results, it was found necessary to project graphically both the dry and moist thermometer observations, Nos. I. II. III. IV. Plate XVIII., and to run curves freely amongst the points. The values for the whole hours are thus obtained in Tables A. and B, and the elasticities of vapour for those hours are thence computed.

† Supplementary Report on Meteorology, British Association Report, 1840, p. 98; and Royal Society's Instructions.

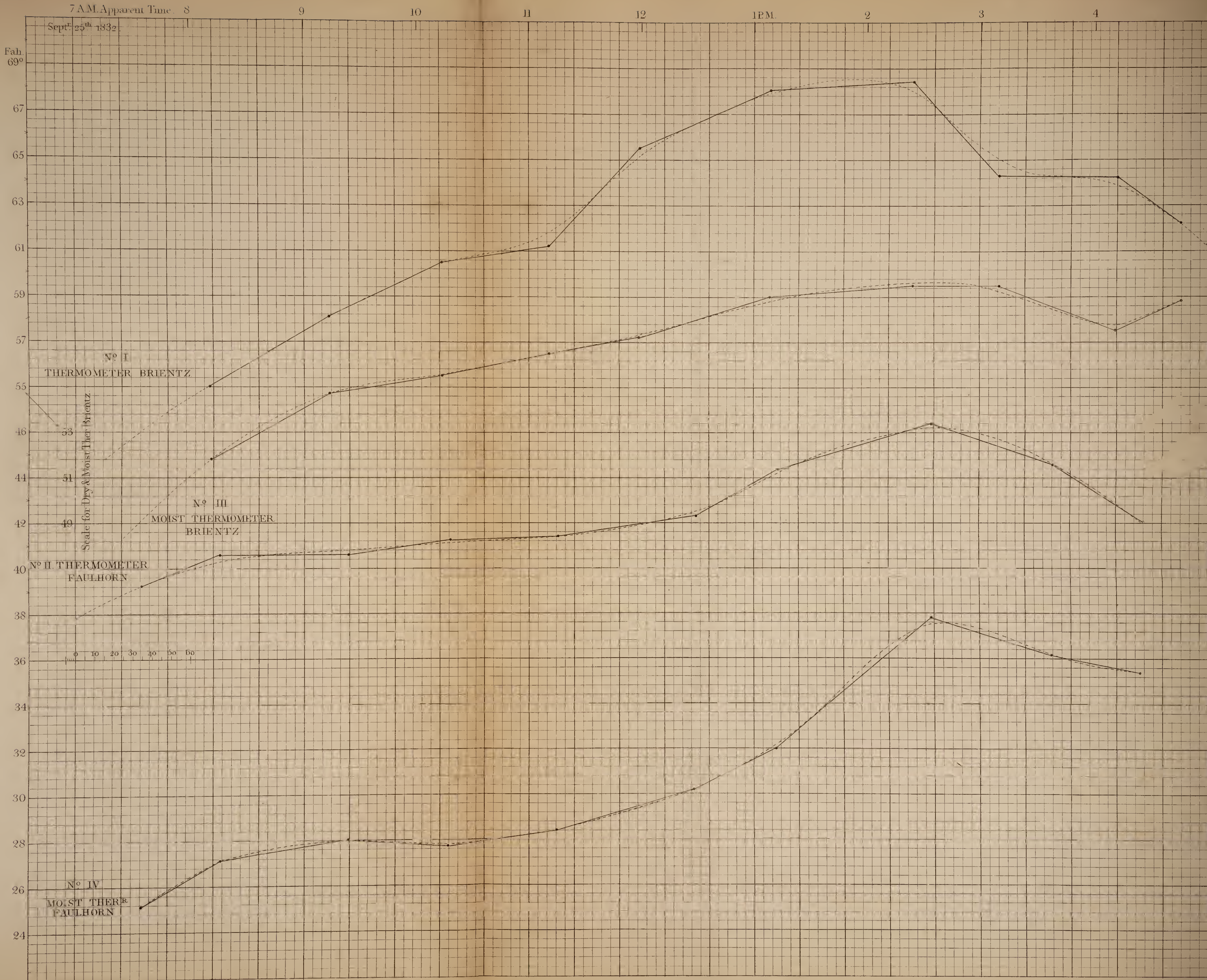
Table B.—Meteorological Observations at the Faulhorn, September 25, 1832.

Mean time.	Apparent time.	Barometer, French lines at 0° Cent.	Barometer, millimetres at 0° Cent.	Detached Therm. Reaum.	Moist Therm. Reaum.	Detached Therm. Fahr.	Moist Therm. Fahr.	Diff.	Elasticity of vapour.	Relative dampness.
h m	h m								inch.	
7 26	7 34	247·13	557·49	3°·2	−3°·1	39°·2	25°·1	14°·1	·038	$\frac{\cdot038}{\cdot257} = \cdot148$
8 7	8 15	247·15	557·53	3·8	−2·2	40·6	27·1	13·5	·053	$\frac{\cdot053}{\cdot270} = \cdot196$
9 15	9 23	247·24	557·73	3·8	−1·8	40·6	28·0	12·6	·067	$\frac{\cdot067}{\cdot270} = \cdot248$
10 9	10 17	247·34	557·96	4·1	−1·9	41·2	27·7	13·5	·057	$\frac{\cdot057}{\cdot276} = \cdot206$
11 7	11 15	247·33	557·94	4·2	−1·6	41·4	28·4	13·0	·065	$\frac{\cdot065}{\cdot278} = \cdot234$
0 21	0 29	247·28	557·82	4·6	−0·8	42·3	30·2	12·1	·086	$\frac{\cdot086}{\cdot286} = \cdot301$
1 4	1 12	247·18	557·60	5·5	0·0	44·4	32·0	12·4	·096	$\frac{\cdot096}{\cdot308} = \cdot312$
2 27	2 35	247·15	557·53	6·4	+2·6	46·4	37·8	8·6	·172	$\frac{\cdot172}{\cdot330} = \cdot521$
3 30	3 38	246·99	557·17	5·6	+1·8	44·6	36·1	8·5	·160	$\frac{\cdot160}{\cdot310} = \cdot516$
4 16	4 24	246·90	556·99	4·5	+1·5	42·1	35·4	6·7	·169	$\frac{\cdot169}{\cdot284} = \cdot595$

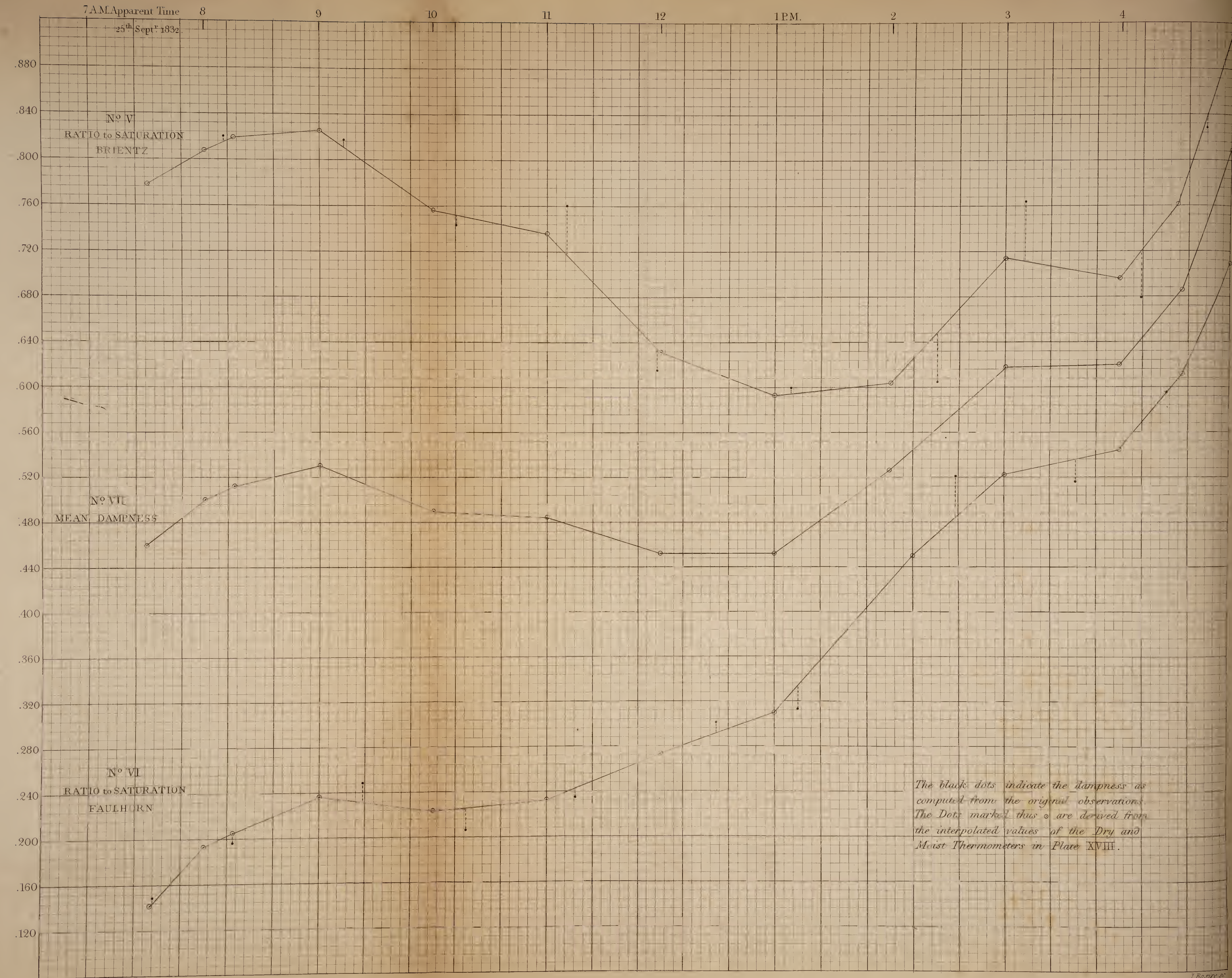
61. The following Tables contain the observations with the actinometers at each station; those at the lower, made with the instrument G. 7, are made comparable to those at the upper with the actinometer B. 2, by the application of the constant factor 1·168 already found. It has been already stated that the day was cloudless; that the observations were made entirely in the open air at the Faulhorn: those at Brientz were made in a room until one o'clock, and afterwards in the open air. For the sake of brevity, the results only are given, and not the readings upon which they are founded.

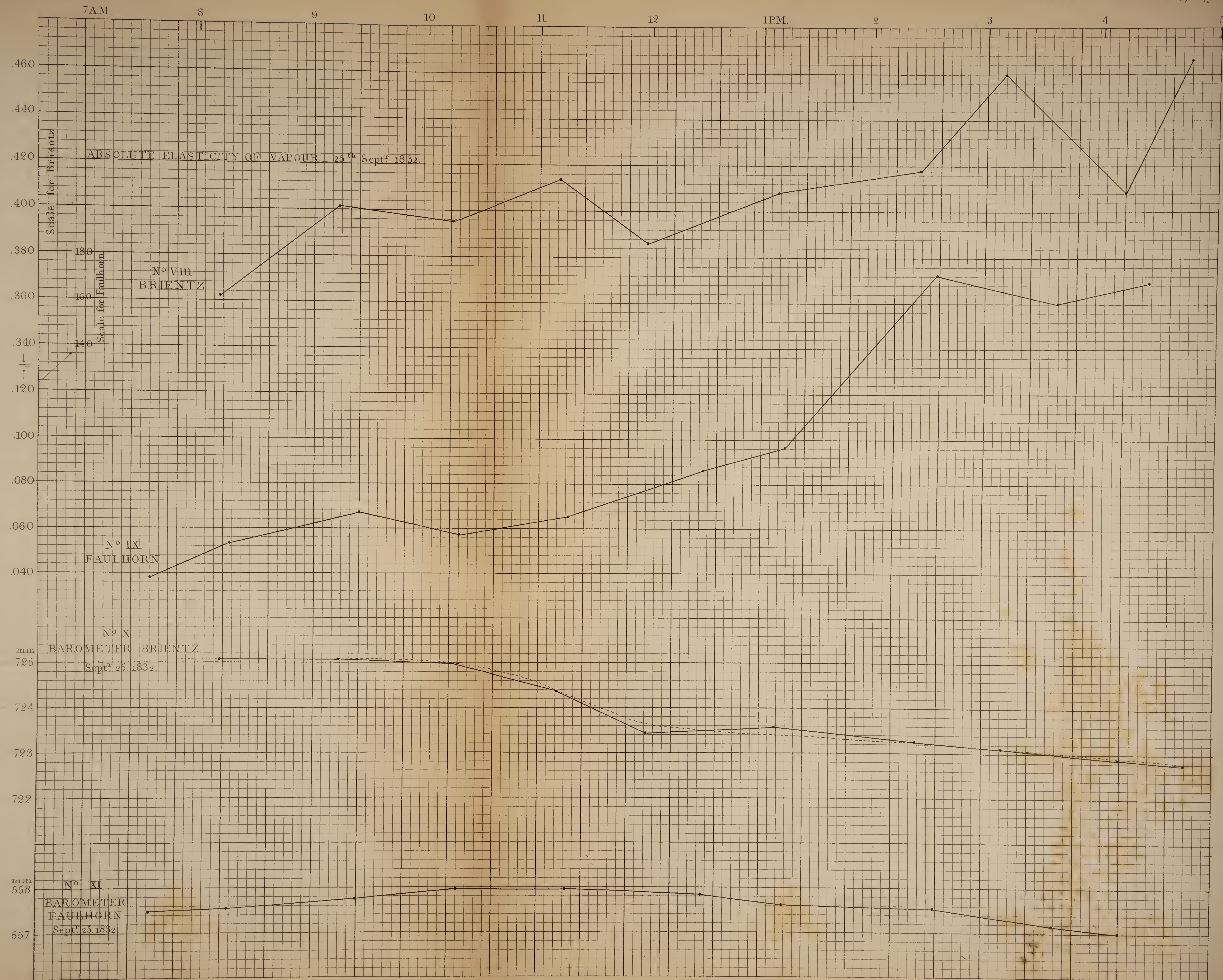
Table C.—Actinometer Observations at Brientz, September 25, 1832.

Hour. From	Hour. To	Hour. Mean.	Apparent time.	Intervals observed.	Actinometer G. 7.	Mean.	Reduced to 60 sec.	Reduced to B. 2.	Remarks.
h m	h m	h m	h m	s					
8 2	8 11½	8 6¾	8 14¾	60	18·7; 19·0; 19·7; 20·7;	19·5	19·5	22·8	
9 5	9 14½	9 9¾	9 17¾	60	22·9; 22·2; 22·9; 22·8;	22·7	22·7	26·5	
10 5	10 15	10 10	10 18	60	23·3; 23·5; 24·4; 24·3;	23·9	23·9	27·9	
11 3	11 15	11 9	11 17	60	24·2; 24·6; 25·2; 25·3; 25·2;	24·9	24·9	29·1	
11 50	12 5½	11 57¾	12 5¾	60	26·0; 26·8; 26·7; 25·8; 26·1; 26·8;	26·4	26·4	30·8	In a room.
12 5½	12 19	12 12¼	12 20¼	60	26·3; 25·1; 26·7; 27·1; 27·4; 26·8;	26·9	26·9	31·4	
12 19	12 24½	12 21¾	12 29¾	30	25·4; 25·2; 25·0; 23·3;	24·7	27·5	32·1	
1 1	1 12½	1 6¾	1 14¾	60	26·2;? 26·6; 26·4; 27·7; 27·3;	26·8	26·8	31·3	
2 17½	2 28½	2 23	2 31	60	21·7; 21·3; 21·3; 21·0;	21·3	21·3	24·9	
3 2	3 11	3 6½	3 14½	60	20·8; 20·7; 20·5; 20·9;	20·7	20·7	24·2	Out of doors.
4 4½	4 15½	4 10	4 18	60	15·8; 15·1; 15·4; 15·3;	15·4	15·4	18·0	
4 38½	4 42½	4 40½	4 48½	60	11·1; 9·9;	10·5	10·5	12·3	


7 A.M. Apparent Time. 8
9
10
11
12
1 P.M.
2
3
4
5
Sept.r 25th 1832.
Fah.
69°
67
65
63
61
59
57
55
53
51
49
46
44
42
40
38
36
34
32
30
28
26
24
Nº I
THERMOMETER BRIENTZ
Scale for Dry & Moist Ther. Brientz
Nº III
MOIST THERMOMETER
BRIENTZ
Nº II. THERMOMETER
FAULHORN
0 10 20 30 40 50 60
Nº IV
MOIST THER.R
FAULHORN

J. Basire sc.


7 A.M. Apparent Time
25th Sept.r 1832.
8
9
10
11
12
1 P.M.
2
3
4
5
.880
.840
.800
.760
.720
.680
.640
.600
.560
.520
.480
.440
.400
.360
.320
.280
.240
.200
.160
.120
No. V
RATIO to SATURATION
BRIENTZ
No. VII.
MEAN DAMPNESS
No. VI
RATIO to SATURATION
FAULHORN
The black dots indicate the dampness as computed from the original observations. The Dots marked thus ⊙ are derived from the interpolated values of the Dry and Moist Thermometers in Plate XVIII.
J. Basire sc.


ABSOLUTE ELASTICITY OF VAPOUR _ 25th Septr. 1832.
7 A.M.
8
9
10
11
12
1 P.M.
2
3
4
5
Scale for Brientz
Scale for Faulhorn
.460
.440
.420
.400
.380
.360
.340
.120
.100
.080
.060
.040
180
160
140
No. VIII.
BRIENTZ
No. IX.
FAULHORN
No. X.
mm
BAROMETER BRIENTZ
Septr. 25. 1832.
725
724
723
722
mm
558
557
No. XI.
BAROMETER
FAULHORN
Septr. 25. 1832.

J. Basire sc.

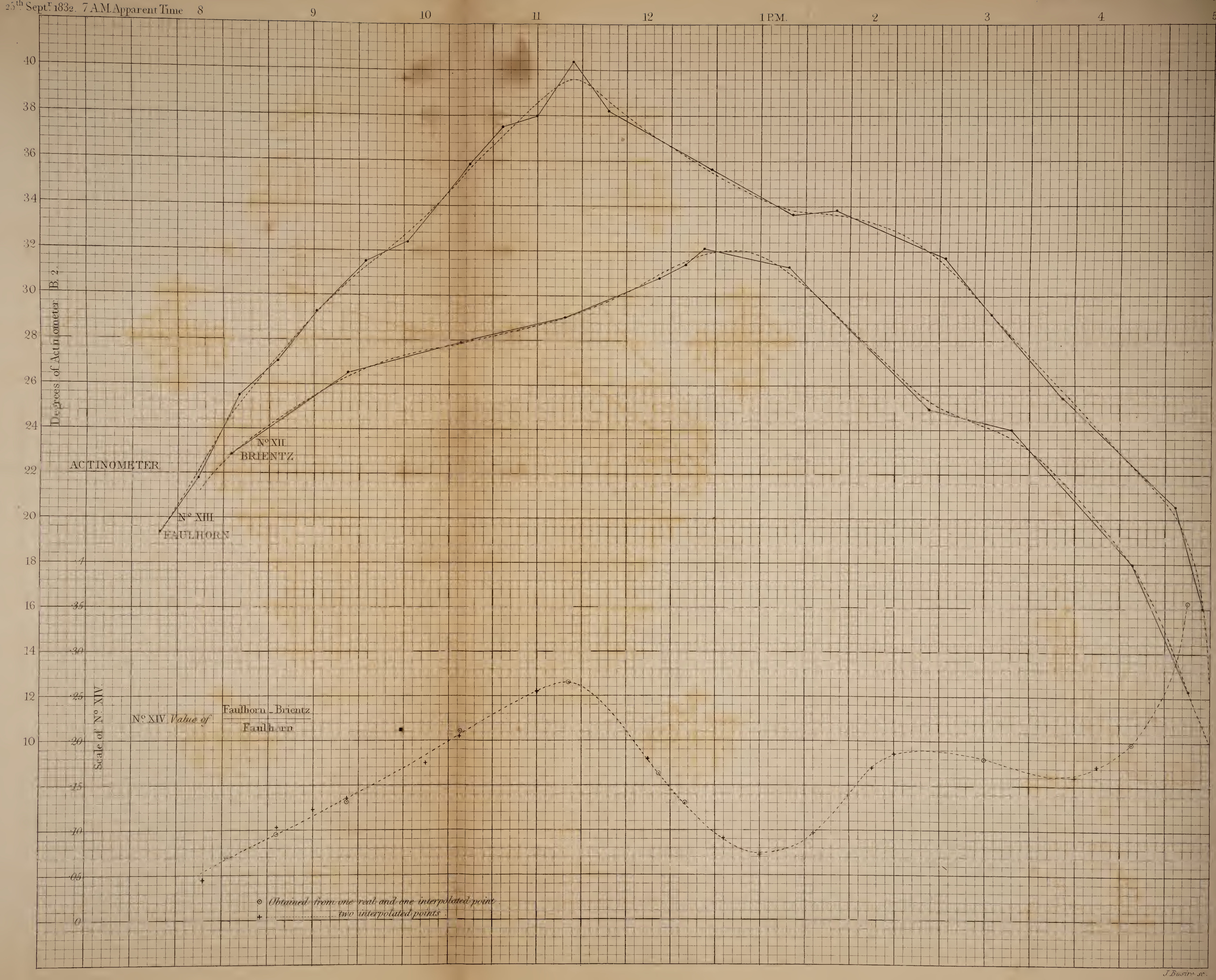

25th Sept. 1832. 7 A.M. Apparent Time
8
9
10
11
12
1 P.M.
2
3
4
5
Degrees of Actinometer B. 2.
ACTINOMETER
No XII
BRIENTZ
No XIII
FAULHORN
Scale of No XIV
No XIV Value of (Faulhorn - Brientz)/Faulhorn
Obtained from one real and one interpolated point
two interpolated points
J. Basire sc.

Table D.—Actinometer Observations at the Faulhorn, September 25, 1832.

Hour. From	Hour. To	Hour. Mean.	Apparent time.	Intervals observed.	Actinometer B. 2.	Mean.	Remarks.
h m	h m	h m	h m	s			
7 26	7 35½	7 30¾	7 38¾	60	16·4; 16·9; 17·6; 18·2;	17·3	
7 46	7 55½	7 50¾	7 58¾	60	21·6; 20·9; 21·7; 22·8;	21·8	
8 7½	8 17	8 12¼	8 20¼	60	25·7; 25·8; 25·4; 25·0;	25·5	
8 28	8 37½	8 32¾	8 40¾	60	26·3; 26·4; 27·9; 27·8;	27·1	
8 48½	8 58	8 53¼	9 1¼	60	27·1; 28·7; 29·2; 31·9;	29·2	
9 15½	9 24½	9 20	9 28	60	30·6; 31·0; 31·8; 32·7;	31·5	
9 37½	9 46½	9 42	9 50	60	31·9; 32·1; 32·5; 33·1;	32·4	
10 9	10 18	10 13½	10 21½	60	36·9; 34·7; 36·0; 35·6;	35·8	
10 29½	10 38¼	10 34	10 42	60	38·0; 36·8; 36·4; 38·6;	37·5	
10 47½	10 56½	10 52	11 0	60	38·7; 37·3; 38·1; 38·0;	38·0	All in the open air.
11 7	11 16¼	11 11½	11 19½	60	39·2; 40·3; 40·8; 41·3;	40·4	
11 26½	11 35½	11 31	11 39	60	38·2; 38·9; 38·2; 37·4:	38·2	
12 21	12 30½	12 25¾	12 33¾	60	35·1; 36·3; 35·3; 35·6;	35·6	
1 4½	1 14	1 9¼	1 17¼	60	32·3; 31·7; 35·1; 35·1;	33·6	
1 27½	1 37	1 32¼	1 40¼	60	32·2; 33·8; 34·2; 34·8;	33·8	
2 27	2 36½	2 31¾	2 39¾	60	31·5; 31·1; 31·0; 33·0;	31·7	
2 47½	2 54½	2 51	2 59	60	29·7; 30·2; 28·9;	29·6	
3 30	3 39	3 34½	3 42½	60	25·0; 26·5; 24·9; 25·2;	25·4	
4 16½	4 25½	4 21	4 29	60	21·3; 20·2; 20·1; 20·6;	20·6	
4 43½	4 52½	4 48	4 56	60	16·5; 16·2; 15·5; 15·8;	16·0	

62. As the observations above and below are nearly contemporaneous, we might readily enough proceed to compare them directly. But I have thought it more exact, and also more instructive, to tabulate the meteorological and other data in the form of curves, and by graphical interpolation to obtain the desired quantities for the *whole* hours, by which means the errors of observation, and also local and momentary atmospheric changes are in some measure eliminated, and a kind of approximation made as to the mean condition, at any moment, of the mass of air under experiment, 6800 feet in thickness, with respect to density, temperature, moisture, and opacity. The great advantages of this method will be seen in the sequel. The curves numbered I. to XIV. in Plates XVIII. to XXI. represent this interpolation, the points of observation being always connected by straight lines, and then a curve drawn easily through them. When reduced again to numbers, we have these regulated data contained in the following Table, from which are deduced,—1st, the intercepted mass of air; 2nd, the mean temperature of the mass of air; 3rd, its mean relative dampness or ratio to saturation; 4th, the loss of solar intensity in the passage of the rays from the level of the upper to the lower station; 5th, the ratio of the intensity at the upper to that at the lower station. This Table also contains,—6th, the sun's *apparent* altitude for every hour of apparent time computed by the usual formula from the hour-angle, corrected for refraction and for the change of declination; 7th, the approximate measure of the total mass of air traversed by the ray with the varying obliquity at each station; 8th, the difference of the two last determinations which gives the effective mass interposed between the stations. These masses of air are supposed to vary as the secant of the zenith distance (see Art. 33.).

TABLE E.—September 25, 1832.

Apparent time.	Brientz.					Faulhorn.					Difference, Dry and Moist Thermometers.		Mean Temp. FAHR.	Difference of Pressure.	[c]	Loss of solar intensity.	Ratio of actinometers $\frac{b}{a}$.	Ratio of loss to effect at Upper Station*.	Sun's apparent altitude.	Barometer × sec. Z. D.		[d]	$c \times d$.
	Barometer at 0° C.	Therm. FAHR.	Moist Therm. FAHR.	Ratio to saturation.	[a] Actinometer, B. 2.	Barometer at 0° C.	Therm. FAHR.	Moist Therm. FAHR.	Ratio to saturation.	[b] Actinometer, B. 2.	Brientz.	Faulhorn.			Mean dampness.					Brientz.	Faulhorn.	Diff.	
$7\frac{1}{2}$	mm 725·06	52·8?	49·0	·779	....	mm 557·49	39·1	24·9	·141	18·2?	3·8	14·2	45·9	mm 167·57	·460	....	......	......	14° 42′	mm 2857·0	mm 2197·0	660·0	303·6
8	725·06	54·5	51·1	·807	....	557·53	40·0	26·5	·193	22·2	3·4	13·5	47·2	167·53	·500	....	......	......	19 26	2179·0	1675·8	503·2	251·6
$8\frac{1}{4}$	725·06	55·3	52·1	·819	22·8	557·53	40·4	27·1	·205	24·5	3·2	13·3	47·8	167·53	·512	1°·7	1·075	·0694	21 48	1952·2	1501·4	450·8	230·8
9	725·06	57·5	54·3	·825	25·5	557·69	40·7	27·9	·236	29·1	3·2	12·8	49·1	167·37	·530	3·6	1·141	·1237	28 18	1529·2	1176·4	352·8	187·0
10	725·03	60·1	55·4	·756	27·6	557·89	41·0	27·8	·223	33·5	4·7	13·2	50·5	167·14	·489	5·9	1·214	·1761	35 39	1244·1	957·3	286·8	140·2
11	724·57	61·5	56·3	·736	28·7	557·96	41·3	28·2	·232	38·6	5·2	13·1	51·4	166·61	·484	9·9	1·345	·2565	40 38	1112·6	856·8	255·8	123·8
12	723·68	65·2	57·3	·631	30·6	557·87	41·9	29·4	·273	37·3	7·9	12·5	53·5	165·81	·452	6·7	1·219	·1796	42 24	1073·2	827·4	245·8	111·1
1	723·42	67·7	58·6	·593	31·8	557·64	43·7	31·5	·310	34·3	9·1	12·2	55·7	165·78	·451	2·5	1·078	·0729	40 37	1111·2	856·7	254·5	114·8
2	723·30	68·5	59·5	·603	27·6	557·55	45·7	35·8	·450	33·3	9·0	9·9	57·1	165·75	·526	5·7	1·207	·1712	35 36	1242·5	957·9	284·6	149·7
3	723·16	65·6	59·5	·713	24·2	557·37	45·9	37·3	·522	29·5	6·1	8·6	55·7	165·79	·617	5·3	1·219	·1796	28 14	1528·7	1178·3	350·4	216·2
4	722·95	64·1	57·8	·696	19·9	557·09	43·5	35·7	·544	24·0	6·3	7·8	53·8	165·86	·620	4·1	1·206	·1708	19 20	2183·7	1683·1	500·6	310·4
$4\frac{1}{2}$	722·85	63·1	58·2	·759	16·2	556·91	41·7	35·4	·611	21·4	4·9	6·3	52·4	165·94	·685	5·3	1·321	·2477	14 34	2874·0	2214·5	659·5	451·7
5	722·75?	61·2?	59·5	·910	10·0?	556·73	39·7	35·2	·709	12·0?	1·7	4·5	50·4	166·02	·809	2·0?	1·200?	·1667?	9 34	4348·8	3350·2	998·6	807·9

* Projected in Curve XIV.

Section V.—*Analysis of the Observations of the* 25*th of September*, 1832.

63. Looking first to the *differential* observations, or the comparative results of those at the two stations, we observe with respect to the solar intensities at Brientz and the Faulhorn as contained in Table E, and as projected in Plate XXI.,—1st, that the intensity at the higher station always exceeded that at the lower by a very appreciable quantity, varying from nearly ten to nearly two degrees of the actinometer B. 2; 2nd, that this loss, compared to the intensity at the higher station, varied from $\frac{7}{100}$ or $\frac{1}{14}$th of the total amount, to above $\frac{25}{100}$th or one-fourth of the total amount; 3rd, that this relative loss appears to have varied rather irregularly, having two maxima nearly equal at 11 A.M. and $4\frac{1}{2}$ P.M.

64. If (without inquiring for the moment into the cause and measure of this variation of effect) we simply seek to deduce a mean value for the opacity of the atmosphere for the entire day of the 25th of September, 1832, we may do so in the following manner:—

65. Let the intensity of the sun's rays at the upper station be denoted by 1, and let its varying value be v: then let x measure the mass of air traversed, measured by an equiponderant column in millimetres of mercury; further, let m be a constant. On the hypothesis of uniform opacity,

$$-d\,v = m\,.\,v\,d\,x \quad \ldots\ldots \quad (1.)$$

$$-\frac{dv}{v} = m\,d\,x$$

$$\log\frac{1}{v} = m\,x. \quad \ldots\ldots \quad (2.)$$

Any number of such observations being made giving corresponding values of v and x, by summation

$$\Sigma\log\frac{1}{v} = m\,\Sigma\,x;$$

whence

$$m = \frac{\Sigma\log\frac{1}{v}}{\Sigma\,x}, \quad \ldots\ldots \quad (3.)$$

where m may be a constant adapted to the tabular instead of hyperbolic logarithms.

66. If the measure of opacity sought (which is that to which we shall generally refer) be the residual intensity of the sun's rays, after passing vertically through a mass of air which balances 760 millimetres of mercury, and if this residual intensity be $[v]$, we shall have by (2.)

$$\log\frac{1}{[v]} = \frac{\Sigma\log\frac{1}{v}}{\Sigma\,x} \times 760. \quad \ldots\ldots \quad (4.)$$

67. If we wish to find the mean condition of the air traversed relatively to contained moisture, we evidently must not take the mean hygrometric result, but consi-

der the proportion which the masses of air obliquely traversed, and having a certain mean dampness, bear to the shorter ones with a different dose of moisture. The average dampness of the whole mass of air penetrated will be

$$\frac{\text{sum of (masses of air} \times \text{dampness of each)}}{\text{sum of masses of air}}.$$

If δ be the ratio to saturation at any hour, δ_1 the mean ratio required, and x the varying mass of air as before, we shall have

$$\delta_1 = \frac{\Sigma\, x\, \delta}{\Sigma\, x} \quad \ldots \ldots \ldots \ldots \ldots \quad (5.)$$

68. The following Table, resuming the results of Table E, contains these quantities.

TABLE F, 25th Sept. 1832.

Apparent time.	$\frac{1}{v}$.	$\log\frac{1}{v}$.	x.	$m = \frac{\log\frac{1}{v}}{x}$.	Dampness δ.	$x\,\delta$.
h m			mm.			
8 15	1·075	·0312	450·8	·0000692	·512	230·8
9	1·141	·0573	352·8	·0001624	·530	187·0
10	1·214	·0841	286·8	2932	·489	140·2
11	1·345	·1287	255·8	5031	·484	123·8
12	1·219	·0860	245·8	3499	·452	111·1
1	1·078	·0327	254·5	1285	·451	114·8
2	1·207	·0815	284·6	2864	·526	149·7
3	1·219	·0860	350·4	2454	·617	216·2
4	1·206	·0814	500·6	1626	·620	310·4
4 30	1·321	·1209	659·5	1833	·685	451·7
Sums		·7898	3641·6	....	....	2035·7

The solution is

$$\log\frac{1}{[v]} = \frac{\cdot 7898}{3641\cdot 6} \times 760 = \cdot 164831,$$

$$\frac{1}{[v]} = 1\cdot 46161,$$

$$[v] = \cdot 68418,$$

Mean dampness of intercepted column δ_1 $\Big\} = \cdot 559013.$

69. Hence it appears that, *on the hypothesis of uniform opacity, a standard atmosphere of* 760$^{\text{mm}}$, *or* 29·922 *English inches of mercurial pressure, and having a mean dampness or ratio to saturation represented by* ·56 *nearly, would transmit* 68½ *per cent., or stop* 31½ *per cent. of the incident heating rays*, an estimate which agrees nearly with the mean of the results of BOUGUER and LAMBERT, and mentioned above, and very closely with the separate and indirect results obtained by Professor KÄMTZ alone on this very occasion*. This confirmation is interesting, perhaps unexpected, as the present is I believe the very first *direct* measurement of the kind.

* His estimate is ·68, not deduced from this day's observations alone, but from an extensive series.

70. Let us now examine the separate data which we have thus massed together.

71. It is evident from the equations last written, that

$$\frac{\log \frac{1}{v}}{x} = m$$

ought to be constant upon the hypothesis which we have provisionally adopted (that of uniform opacity and of uniformity of meteorological conditions). If, however, we divide the numbers in column 3 of Table F by those in column 4 (as is done in column 5), we shall find wide differences for the value of m. These may arise,—1st, from changes in the constant of opacity m, which may naturally arise from meteorological variations; 2ndly, from an error in the logarithmic hypothesis, which is founded on the physical supposition of a loss continually proportional to the intensity; 3rdly, from errors of observation. We shall consider these causes in succession.

72. I. The most important meteorological element is undoubtedly the dampness of the air; for we *know* that the formation of the slightest visible vapour instantly diminishes the solar intensity. We can hardly doubt that this action must depend upon the relative dampness of the atmosphere, that is, upon the portion of moisture existing, compared to what could exist without deposition in an equal space, and not upon the *absolute elasticity* of the vapour: for it is plain that vapour of given elasticity would make a dense visible cloud at one temperature, and might yet be compatible with intense relative dryness at another. I have therefore taken particular pains in the reduction of the hygrometric observations, and the course of the progress of dampness at Brientz and the Faulhorn in curves V. and VI. is particularly worthy of observation. At the former, the *lower* station, the dampness is greatest in the morning and evening, and has a minimum between 1 and 2 P.M. At the *upper* station, on the contrary, the dampness increases almost continually from morning till night. These facts are perfectly normal*, and are readily explained by the continual rise of the imperfectly condensed moisture which occupies the valleys of the Alps every fine night in summer, and is gradually exhaled into the upper atmosphere by the action of currents and the increasing warmth of the inferior strata,—a phenomenon from which arises (amongst other effects) the very frequent formation, about noon in the finest weather, of clouds at a height of from 8 to 15000 feet, which again give way during the advance of evening as the vapour descends.

73. The curve of mean dampness at both stations (VII.) exhibits a morning and afternoon maximum about 9 A.M. and 3 P.M., preceding somewhat the epochs of maximum loss of solar radiation already referred to. This is an important analogy, and an inspection of Curve VII. together with Curve XIV., which represents the loss of solar radiation in terms of the radiation at the upper station, will show a certain general, though not a precise analogy.

74. It cannot, however, be affirmed that these experiments are at all sufficient to show the kind of dependence which the Opacity has upon the Dampness. The values

* See DOVE's Repertorium, iv. 264.

of m, which we may call the *coefficient of extinction*, do not present any correspondence with the hygrometric variations. It is to be desired, however, that such curves should be extensively constructed.

75. II. It has been assumed that the mass of air intercepted between Brientz and the Faulhorn was equal to the differences of the barometers multiplied into the secant of the zenith distance of the sun (Art. 33.). It does not appear, however, that the ratio of heat reaching the lower station, compared with that at the upper one, varies in a geometrical progression when the thicknesses vary arithmetically. But we can hardly thence argue against the hypothesis of uniform *proportional* extinction, because the law of continuity is evidently not preserved.

76. III. Are the variations of m from hour to hour to be considered as merely the result of errors of observation? I apprehend that in some measure they may fairly be so considered, especially as resulting from a slight discontinuity in the observations at Brientz before and after one o'clock, the former being made within doors, the latter without; but the real analogy must evidently be of a somewhat complicated kind. A narrow inspection of the actinometric curves XII. and XIII., will illustrate this. It is one of the admirable results of graphical analysis, that we seize the slightest symmetry in the form of functions which might otherwise appear very dissimilar.

77. Viewed generally, we observe in these curves, *first*, that they differ from the common diurnal temperature curves (which approach more or less to the curve of sines) by drooping more rapidly at each extremity; *secondly*, that both curves have a morning and afternoon inflection before and after they attain their maximum; *thirdly*, that the curve of intensities at the upper station lies *wholly above* the curve for the lower station; *fourthly*, that the range of the former curve is greater than that of the latter; *fifthly*, that the maximum is sooner attained in the former than in the latter case.

78. Now the three geometrical characteristics last mentioned, make it plain that the *law of the differences* between the two curves must be a complex one. The analogy is very striking with the inquiry into the law of the decrement of temperature in the atmosphere at different hours and seasons, which I have fully considered in a paper in the Edinburgh Transactions*. I might, as in that case, reduce these curves to series of functions of sines, and show that the differential curve, having generally the same form, would admit of various maxima and minima in the course of the day, but I apprehend that for a single day's observations the numerical results could not have much value. I am quite confident, however, that the *five* peculiarities just mentioned of these curves will be found to be reproduced in every series made under equally favourable circumstances. If this be the case, the seeming irregularities which we are considering will be resolved into the more general consideration of the physical causes of the form of the actinometric curves. I shall make a very few remarks on each of the peculiarities above noticed.

* Vol. xiv. p. 489.

79. First. The rapid fall of the actinometric curves is due to the extreme rapidity with which the length of path increases as the sun approaches the horizon. They differ from the curve of air temperature, because that is a slow and gradual result of complicated actions; the coolness of evening is a *continuous* result; but the disappearance of the sun under the horizon corresponds to an instant extinction of the force of radiation. Secondly. With respect to the points of contrary flexure which occur about two hours before and after their maximum values, and which in both curves are slightly marked in the morning, and more intensely in the afternoon, they probably arise from the combination of a two-fold effect of the sun's elevation. The one is the increased intensity as the sun is higher, the other is the transference of vapour from the lower to the higher regions of the air by the heating of the lower strata, producing the incipient condensation at a certain elevation, already alluded to as the cause of the slight clouds which often appear between ten and twelve o'clock. As the sun's power diminishes, and the vapours redescend into the less rarefied and warmer regions, they are in some degree redissolved in the afternoon, and the increased transparency of the atmosphere (which will besides be aided by the general maximum of the temperature of the air occurring in the plains between two and three o'clock, and producing also a maximum of dryness there) checks the downward progress of the curve due to the increasing obliquity of the rays. Thirdly. The curve at the upper station lies wholly above that at the lower station, on account of the absorption of heat in every case by the intercepted air. Fourthly. The range at the higher station is greater than that at the lower. This is an evident and necessary consequence of the fact, that the maximum above must exceed the maximum below, and that at sunset and sunrise they must both pass through zero. It might be more correct, however, to consider the continuous part of the curve extending to the moment *before* sunset from the moment *after* sunrise. In this case we might expect the difference of intensity at the two stations to increase very rapidly with the obliquity of the sun's rays, so that the two curves, instead of approaching one another in the morning and evening as they appear to do (Curves XII. and XIII.), ought to separate further. It is to be recollected, however, that the extinction in any stratum varies with the intensity of the *incident* heat, and that being very small near the horizon, the absolute extinction will be very small also. Nevertheless, the *relative* extinction may be very great, as appears from the form of the right-hand branch of Curve XIV. The morning branch does not show the same effect, and this may be thus explained. The evening vapours are dense and absorptive; in the morning the atmosphere is comparatively clear, especially amongst mountains. To this circumstance must be imputed the much more rapid fall of the Curves XII. and XIII. in their evening than their morning branch. But further, it will be shown presently that the law of uniformly regular extinction is not true, and that the loss in passing through a medium, is not only absolutely but relatively (to the intensity) greater at first than afterwards: that when the thicknesses are very great, any additional thickness intercepts but little of the radiant force; conse-

quently, near the horizon, a great thickness of atmosphere having been traversed by the rays which reach the upper station, even the obliquity of the passage to the lower station does not (unless the inferior strata be particularly loaded with vapours), cut off anything like a corresponding portion of solar heat, and a second equal mass would intercept still less.

80. Fifthly, and lastly, the maximum of intensity is sooner attained above than below. This arises, no doubt, mainly from the fact (amply confirmed by the hygrometric curves), that the sun shines with a disproportionate intensity during the morning on the upper station, owing to the mass of vapours being then in the valleys. The solar intensity will therefore attain an earlier maximum, since after ten or eleven o'clock a quantity of vapour rises between the upper station and the limit of the atmosphere, and therefore throws the maximum rather before noon. In the plains, on the contrary, where the *whole* atmosphere is *all day* between the observer and the sun, the maximum will incline towards the period of maximum dryness of the day, that is, it may be an hour or half an hour after noon. The curve of mean dampness VII., with its point of contrary flexure in the afternoon, entirely confirms this view, and the diurnal curve of temperature at Brientz, marked I., shows both inflections in the clearest manner.

81. From the comparison of the two curves of solar intensity, we have deduced the mean loss of heat intercepted between the two stations, and we have thence concluded that, on the hypothesis of uniform opacity, about *one-third* of the solar heat is lost by vertical transmission through the atmosphere. It is interesting to compare this result with that which is deducible from the individual observations at either station. In that mode of viewing the subject, it appears from BOUGUER's reasoning (see Art. 7), that two observations at different altitudes are, in point of rigour, sufficient for deducing the loss due to vertical transmission. If more than two values have been got, they may be combined in two series of which the means are taken; or they may be treated by the method of least squares, which will give the most probable result, on the hypothesis of the diminishing geometrical progression of the intensities. It is more interesting and important, however, to employ the superfluity of observations in testing the accuracy of the assumed law, rather than in giving a merely illusory degree of precision to the results of a law which may be wrong. For this purpose I projected, by rectangular coordinates, the intensities observed, the thicknesses of homogeneous air traversed (computed from the sun's altitude) being the horizontal coordinate or independent variable. On the law commonly assumed, the points thus determined ought to lie in a regular logarithmic curve, which being readily prolonged by geometry or by calculation, would give the intensity corresponding to thickness 0, or the degrees which the actinometer B. 2. would show if placed *wholly beyond the atmosphere.*

82. When the projection came to be made, I remarked, with much interest and some surprise, the admirable agreement between the insulated observations at both

N° XV

INTENSITY OF SOLAR RADIATION,

ON THE SCALE OF ACTINOMETER B. 2 — ON THE 25TH SEPTR 1832.

AT BRIENTZ & THE FAULHORN.

BRIENTZ

Hour Appt Time	Thickness Atmosphere *Millimetres*	Actinometer
8¼	1952	22·8
9	1529	25·5
10	1244	27·6
11	1113	28·7
12	1073	30·6
1	1111	31·8
2	1242	27·6
3	1529	24·2
4	2184	19·9
4½	2874	16·2

FAULHORN

Hour Appt Time	Thickness Atmosphere *Millimetres*	Actinometer
7½	2197	18·2
8	1676	22·2
8¼	1501	24·5
9	1176	29·1
10	957	33·5
11	857	38·6
12	827	37·3
1	857	34·3
2	958	33·3
3	1178	29·5
4	1683	24·0
4½	2214	21·4

The observations at Brientz are distinguished by full lines and black dots, those at the Faulhorn by dotted lines and stars.

stations. Not only did the *continuity* of the law which both series followed prove the exactness of the reduction of intensities obtained with one instrument into degrees of the other, but what I have called *unexpected*, was the fact that an equal ordinate or intensity should be indicated for a passage through an equal *mass* of air at both stations. For that mass of air, it is to be observed, was very differently composed in the two cases. On the Faulhorn, a very oblique transit through the rare air, superior to 8400 feet, was requisite to give the same mass as a less oblique transit through the whole atmosphere, in order to arrive at the lower station. It is very far from evident that an equal loss should take place in both cases: yet when the observations were projected in the form of Curve XV. Plate XXII., without regard to the station at which they were made, they were found to range perfectly well together, so that one and the same interpolating curve passed naturally and easily through either series, or through both.

83. I first sketched by the eye, and without respect to any theory, a curve which appeared to satisfy the observations of the 25th of September, which curve, it is to be observed, was to give the law of extinction of heat in the atmosphere, and by its arbitrary prolongation, to assign the solar intensity beyond the atmosphere, and the absorption due to a vertical transmission.

Sect. VI.—*Concerning the Law of Extinction.*

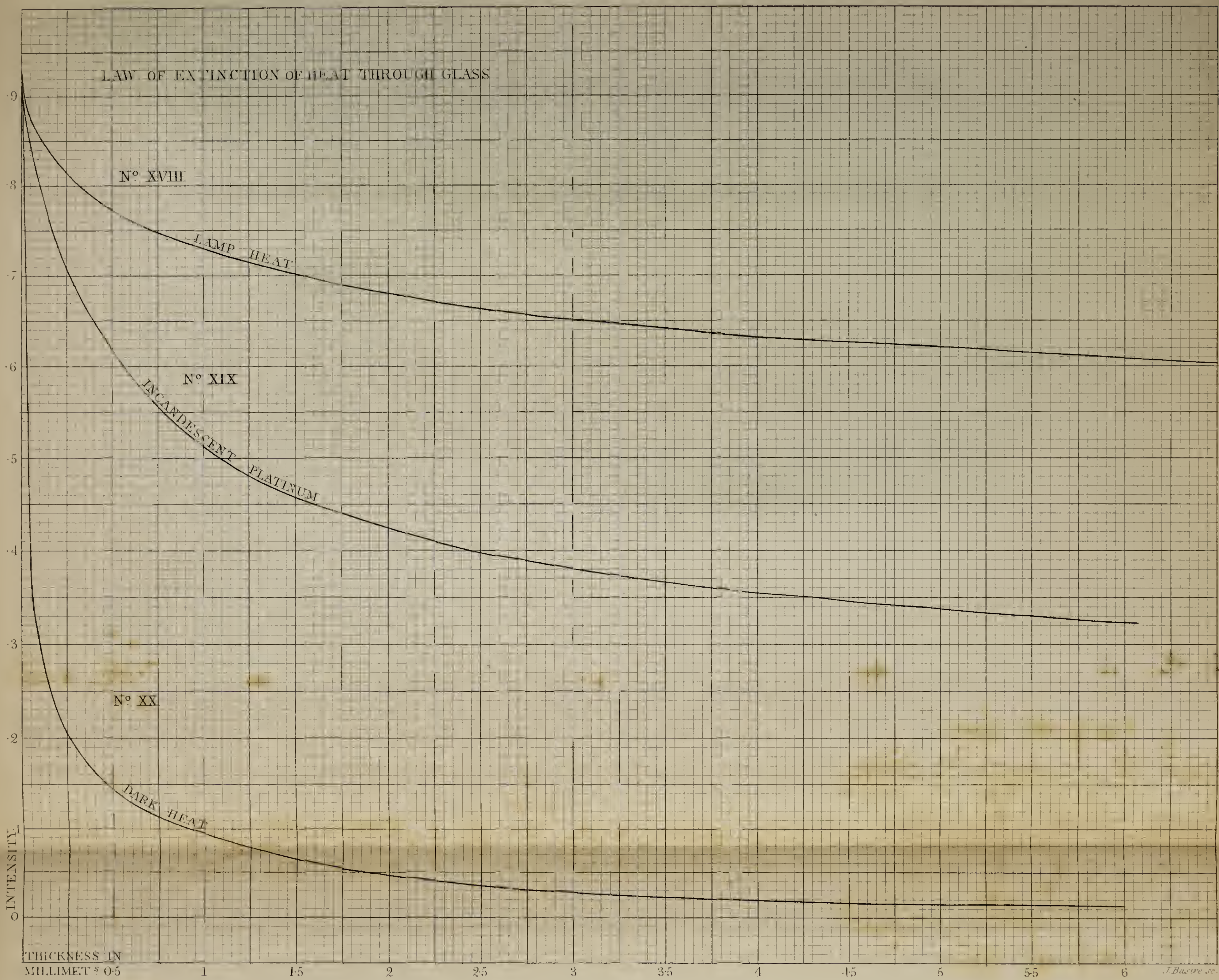
84. Many familiar facts connected with the extinction of heat and light in passing through media, some of which have been adverted to in the earlier part of this paper, render it very unlikely that the part of the solar rays which affects the actinometer should suffer a *uniform relative* loss in the successive strata of air. Perhaps no medium whatever merely extinguishes light without colouring it, and if it colours it, the light, being first deprived of those portions or rays for which the medium in question is comparatively opake, will be more and more freely transmitted through similar successive obstacles. We have seen (Art. 13.) how Lambert established the law of the progressively-increasing diathermancy of successive plates of glass, a result confirmed by De la Roche and Melloni: and as we have found that, notwithstanding the rarity of the atmosphere, its resistance to the passage of even the solar rays is considerable, it is a most probable thing that a similar law should hold in that case. A very slight inspection indeed of Curve XV. shows that it rises much faster than in a simple geometrical progression. What law will best satisfy the observations? and how far are we justified in pushing it beyond the limits of experience, as for instance, to the surface of the atmosphere?

85. The safest induction would appear to be by endeavouring to generalize the *law of extinction* of heat in various media. But here we are met by peculiar difficulties. A certain number of experiments have been made on the extinction of heat from terrestrial sources in passing through different thicknesses of media, such as glass, rock crystal, or water. I allude particularly to those made by M. Melloni,

at the suggestion of M. BIOT, of which the latter has given an elaborate analysis*. Now when the curves of intensity of transmitted heat are projected in terms of the thickness of the transmitting medium, it appears that the rate of extinction is much more rapid at first, becomes continually slower, and long before the curve has reached the axis, or the heat has been wholly absorbed, it runs parallel to the axis without ever approaching it; in other words, it has an asymptote parallel to, but at a distance from the axis. This corresponds to the physical fact, that when heat has been already transmitted through a great thickness of any medium, provided it be mechanically pure, an increase of thickness will produce little or no extinction.

86. The cases of extinction which I have most narrowly considered are those of lamp-heat, heat from incandescent platinum, and dark heat, through glass. These curves are projected in Plate XXIV., the ordinates representing the intensities of heat transmitted at different thicknesses, the incident heat being unity, but which is reduced to ·925 according to MELLONI, by reflection at the two bounding surfaces. The existence of an asymptote or final value of the transmitted heat in every one of these cases is abundantly evident, and this would be one of the constants (variable for different media) which would determine the equations to the curves, which might be expected to be of one species. There is, however, the utmost difficulty in representing these laws of extinction by one tolerably simple *continuous* form; and however desirable it may be that such a form should be discovered, so that a portion of the system of ordinates being found, the remainder may be deduced, we must admit that there is little physical probability for its permanence. And for this reason: the incident rays may be imagined to be composed of a great, but definite number of portions of radiant matter, of distinct qualities as regards the rate of extinction. We may suppose, for simplicity, that each individual homogeneous ray (or congeries of similar rays) is extinguished according to the simple logarithmic law. But each ray has its own modulus, or coefficient of extinction, which depends on two things, namely, the composition of the incident heat, and the specific nature of the medium, as regards each of the integral kinds of heat. Hence the *initial* rate of extinction will depend almost entirely upon the portion of heat very easily extinguishable, which exists in the calorific beam, and not sensibly upon those *persistent* kinds of heat for which the medium in question is nearly diaphanous; whilst at great thicknesses the former class of rays being entirely extinguished as to sense, the latter class, namely, the more persistent ones, alone exercise any influence on the curve of extinction. Thus it appears, that since we have no *à priori* method of discovering the composition of any mixed kind of heat from such a source as the sun, it must be *impossible* to conclude with certainty the law of loss or extinction at *small* thicknesses, from observations of the law of extinction at *great* thicknesses; for they are not in point of fact the same rays which are undergoing extinction in the one case and in the other, and therefore the continuity of the law cannot be assumed with any degree of certainty. The indication of

* Mémoires de l'Academie des Sciences, tom. xiv. p. 493, &c. (printed in 1838).


LAW OF EXTINCTION OF HEAT THROUGH GLASS
N° XVIII
LAMP HEAT
N° XIX
INCANDESCENT PLATINUM
N° XX
DARK HEAT
INTENSITY
THICKNESS IN MILLIMETS
·9
·8
·7
·6
·5
·4
·3
·2
·1
0
0·5
1
1·5
2
2·5
3
3·5
4
4·5
5
5·5
6

J. Basire sc.

the true law could only, in fact, arise from the minute residual quantity of the more extinguishable rays existing at great thicknesses; quantities so small that the law of their variation would be lost in the errors of observation.

87. The analogy of the case of light will perhaps illustrate this important consideration. Suppose solar light to be incident upon intensely red glass: at very minute thicknesses some part of every kind of light will, no doubt, pass through, but we know that the old veneered homogeneous glass transmits pure red light, even when it is very thin indeed. At still greater thicknesses only red light will be transmitted, and that with as great freedom, perhaps, as common window-glass permits the passage of white light. The intensity then of the red light, for which the glass is perfectly transparent, indicates the *residual* constant quantity, towards which the transmitted beam continually approximates, and which is very far from zero of intensity. But it is evident that however numerous and complete our observations upon the law of absorption of light (without respect to colour) might be at all but the least thicknesses of such red glass, it would be impossible to deduce from them alone the law of extinction of all those kinds of light for which the medium in question is very nearly opake, as, for instance, the yellow or the blue, and consequently it would be impossible even to approximate to the primitive intensity of the compound incident beam.

88. M. Biot, in the memoir already referred to on M. Melloni's experiments, is so sensible of these difficulties, that he has contented himself with arbitrarily dividing the incident heat into three kinds or qualities as respects extinction, calculating by a separate law for each, and assuming the sum as the representation of the transmitted heat; a process by which, no doubt, almost any series of facts might be represented, and which therefore gives very little information as to the real law of extinction.

89. I have spent much labour on the same subject, of which it would be out of place here to detail the results. I have indeed obtained a form which contains only three constants, and which expresses tolerably the law of extinction of heat in solid media. But this investigation satisfied me that where the medium is so very absorptive as most solids are, it is wholly impossible to deduce the form of the curve near its origin, from the remoter portion of it.

90. However desirable it might be to proceed by the direct analogy of media, for which we may ascertain the law of extinction, to that of the atmosphere, in which we can only ascertain it for certain considerable thicknesses, the circumstances now detailed appear to render an investigation of such generality entirely useless. In the discussion of the Curve XV. I have thrown aside every other consideration, and attempted to obtain an empirical formula which shall satisfy the law of extinction within the very considerable limits of thickness observed on the 25th of September, 1832, viz. from 827 millimetres to 2874 millimetres of mercury for the equiponderant column.

91. A curve, nearly approaching to that of Curve XV., has been drawn through the points therein defined, which curve, as already stated, was drawn by the eye without reference to any theory whatever. Tangents were *mechanically* drawn to this curve, and the *rate of loss* for a given thickness was ascertained corresponding to equal increments of intensity, or for the parallels of 15, 20, 25, 30, 35, 40, and 45 actinometric degrees. For convenience, the rate of loss was found corresponding to 500 millimetres of mass of air in each case, and found to be

$$1^\circ{\cdot}2 \qquad 3^\circ{\cdot}0 \qquad 6^\circ{\cdot}0 \qquad 9^\circ{\cdot}5 \qquad 12^\circ{\cdot}8 \qquad 15^\circ{\cdot}7 \qquad 18^\circ{\cdot}3,$$

numbers nearly in arithmetical progression.

92. The rate of loss in terms of the intensity is projected in Curve XVI., Plate XXIII., and an interpolating straight line has been passed through the points. Now, were the loss everywhere proportional to the intensity, which is the logarithmic law, the straight line would have cut the axis when the intensity $= 0$, whereas the rate of loss vanishes when the intensity $= 14^\circ{\cdot}3$ nearly, which indicates the limit towards which the intensity is continually tending, below which it cannot fall, and which is consequently the position of the asymptote. The equation to this line is of the form

$$x = a\,v - b,$$

where v is the intensity in actinometric degrees, and x being the rate of extinction for *one* millimetre of thickness, $a = {\cdot}001224$, $b = {\cdot}0175032$, whence the rate of extinction for 500 millimetres has been computed, in order to be compared with the graphical results (of which the possible errors, as in every case of drawing tangents, are very sensible).

Intensity.	Rate of loss for 500 millimetres. Observed.	Calculation.	Differences.
° 45	° 18·3	° 18·79	° +0·49
40	15·7	15·73	+0·03
35	12·8	12·67	−0·13
30	9·5	9·61	+0·11
25	6·0	6·55	+0·55
20	3·0	3·49	+0·49
15	1·2	0·42	−0·78

93. Assuming the form of this approximation to be satisfactory (with a slight modification of the constants), we have for the value of the first differential coefficient of the equation to the Curve XV.,

$$-\frac{d\,v}{d\,x} = a\,v - b \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (a.)$$

$$d\,x = -\frac{d\,v}{a\,v - b}.$$

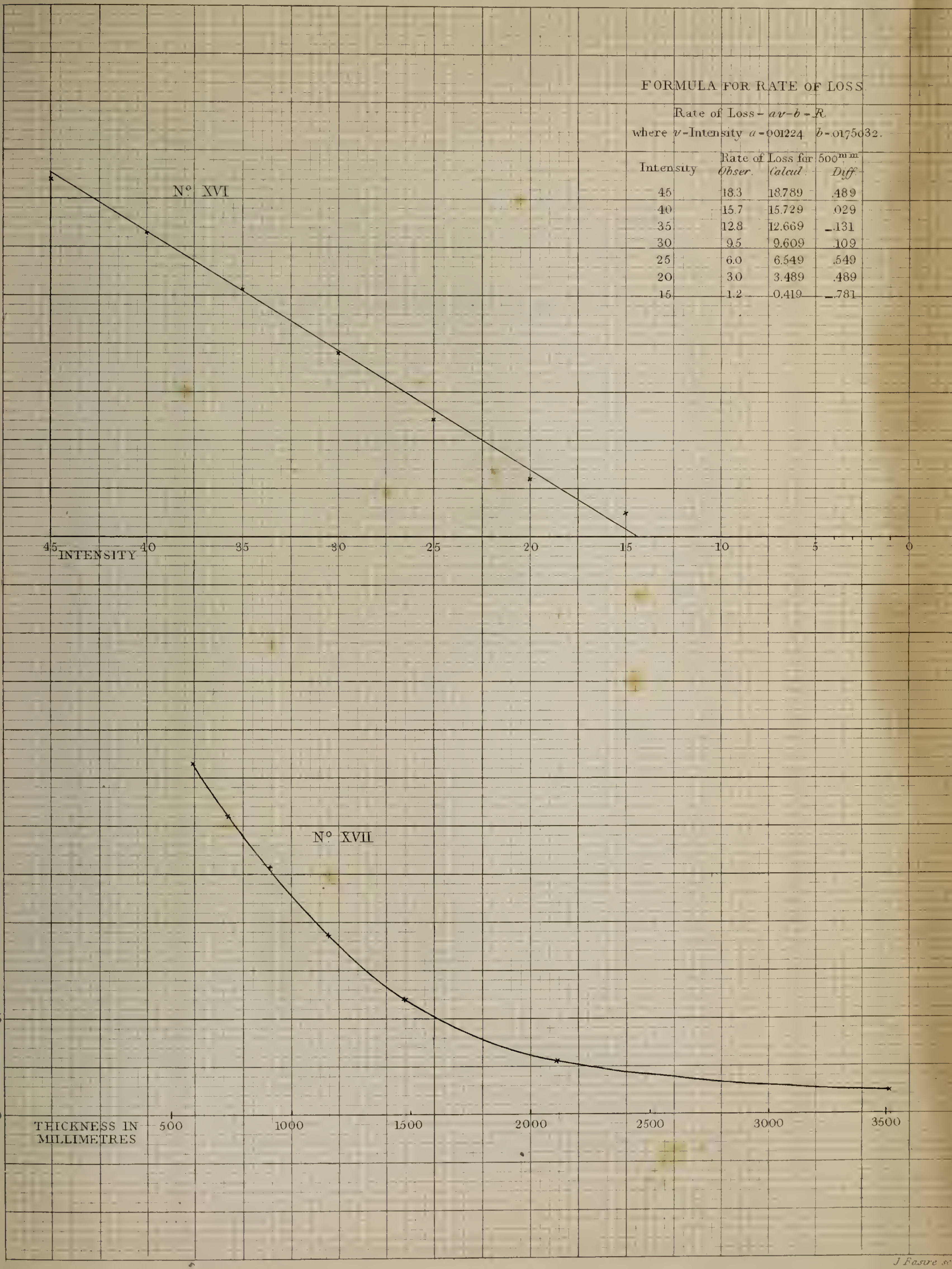
$$x = -\frac{1}{a}\log\left(a\,v - b\right) + c \quad . \quad . \quad . \quad . \quad . \quad (b.)$$

$$= -\frac{1}{a}\log\left(\frac{d\,v}{d\,x}\right) + c \quad . \quad . \quad . \quad . \quad . \quad (c.)$$

LAW OF ABSORPTION OF LIGHT THROUGH THE ATMOSPHERE.

25th Sept.r 1832.

Phil. Trans. MDCCCXLII. Plate XXIII. p. 260.



Intensity	Rate of Loss for 500mm Obser.	Calcul.	Diff.
45	18.3	18.789	.489
40	15.7	15.729	.029
35	12.8	12.669	–.131
30	9.5	9.609	.109
25	6.0	6.549	.549
20	3.0	3.489	.489
15	1.2	0.419	–.781

J. Basire sc.

Whence, if the rate of loss $\frac{d v}{d x}$ be projected in terms of the thickness, as in Curve XVII., it ought to give the logarithmic curve, which it evidently approaches nearly.

94. When $x = 0$, let $v = \mathrm{V}$ the intensity in actinometric degrees exterior to the atmosphere,

$$x = \frac{1}{a} \log \frac{a \mathrm{V} - b}{a v - b}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (d.)$$

When $a v = b$, or $v = \frac{b}{a}, x = \infty, \frac{b}{a}$ is therefore the distance from the horizontal axis to the asymptote.

95. Dividing both numerator and denominator in equation (*d.*) by a, it becomes

$$x = \frac{1}{a} \log \frac{\mathrm{V} - \frac{b}{a}}{v - \frac{b}{a}}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (e.)$$

which is the equation to a logarithmic curve whose general ordinate is $v - \frac{b}{a}$ instead of v. This, therefore, is the form of the curve of extinction in Curve XV.

96. For calculation, (the logarithms being hyperbolic, and ε denoting the base of that system) by equation (*d.*),

$$\varepsilon^{a x} = \frac{a \mathrm{V} - b}{a v - b} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (f.)$$

and any corresponding ordinates v and x being given, as well as the values of a and b, we may deduce the initial value or V in the following terms:—

$$\mathrm{V} = \frac{1}{a} \{ b + (a v - b) \varepsilon^{a x} \} ; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (g.)$$

and taking Tabular Logarithms,

$$\log \left(\mathrm{V} - \frac{b}{a} \right) = \log \left(v - \frac{b}{a} \right) + a x \log \varepsilon. \quad . \quad . \quad . \quad . \quad . \quad . \quad (h.)$$

97. In the construction of the Curve XV., constants a little different from those above found have been used as expressing the *mass* of the observations rather better. The value of $\frac{b}{a}$ instead of 14°·3 has been assumed at 15°·2. A line is drawn parallel to the axis of x at that distance, and a logarithmic curve constructed upon it, with the value of m in equation (1.) Art. 7, which is the same as $a \log \varepsilon$ of equation (h), equal to

·00050708.

The following ordinates have been thence computed.

Thickness, or x in millimetres of mercury.	Intensity, or v in degrees of Actinometer B. 2.
0	57°·86 + 15°·2 = 73°·06
500	32·3 + 15·2 = 47·5
1000	18·0 + 15·2 = 33·2
1500	10·3 + 15·2 = 25·5
2000	5·6 + 15·2 = 20·8

Thickness, or x in millimetres of mercury.	Intensity, or v in degrees of Actinometer B. 2.
2500	$3^{\circ}\cdot1 + 15^{\circ}\cdot2 = 18^{\circ}\cdot3$
3000	$1\cdot7 + 15\cdot2 = 16\cdot9$
infinite	$0\cdot0 + 15\cdot2 = 15\cdot2$

Hence, supposing the approximation to the initial intensity of the solar heat to be sufficient, the portion transmitted through an atmosphere balanced by 760 millimetres of mercury will be found to be

$$\frac{39\cdot03}{73\cdot06} = \cdot534 \text{ of its whole amount.}$$

The value of V is by no means given as certain: it may very probably be *greater*, even *much greater* than has been assigned, but it is very unlikely to be *less*.

98. Hence, too, the absolute intensity of the solar ray has been very much underrated by all writers. The portion vertically transmitted probably does not exceed a half, instead of being equal to two-thirds or three-quarters, as has generally been supposed. BOUGUER's estimate for light approaches nearest to it, but that was founded on the logarithmic law, which we have shown not to be applicable, at least for heat.

99. It may be interesting, however, before finally quitting the observations of the 25th of September, 1832, to inquire what results we should have deduced from them upon the old hypothesis of the intensity diminishing in geometrical progression, and thus to render the observations directly comparable with those of BOUGUER, LAMBERT, LESLIE, KÄMTZ, and POUILLET, that is, so far as I am aware, of every author who has published any determination of the opacity of the atmosphere, including LAPLACE.

100. Resuming the notation of Art. 7, which we used to describe BOUGUER's method, where v_1 and v_2 are two intensities expressed in actinometric degrees, x_1 and x_2 the corresponding atmospheric masses traversed expressed in millimetres of mercury. By equation (3.) of that article* we find the value of the coefficient of extinction

$$m = \frac{\log \frac{v_2}{v_1}}{x_1 - x_2}.$$

And if $[v]$ = the intensity after a vertical transit through the atmosphere, the intensity beyond the atmosphere being = 1, we have by equation (1.) of that article,

$$\log \frac{1}{[v]} = m \times 760.$$

When more than two values of v and x are used we may divide them into two series, and take the arithmetical means of log v and x for each.

101. Now a good deal depends upon the way in which these series are formed. We may combine the observations, so that the observations on the shortest atmospheric columns forming one series shall be set against those of the longest columns in another. Thus the observations at Brientz alone give the following results.

* It will be seen that this equation is obtained in exactly the same way as that of Art. 65.

Brientz.

First Series.			Second Series.		
Hour.	Log v.	x.	Hour.	Log v.	x.
$8\frac{1}{4}$	1·3579	1952	10	1·4409	1244
9	1·4065	1529	11	1·4579	1113
3	1·3838	1529	12	1·4857	1073
4	1·2989	2184	1	1·5024	1111
$4\frac{1}{2}$	1·2095	2874	2	1·4409	1242
Sum.	6·6566	10068	Sum.	7·3278	5783
Mean. . . .	1·3313	2014	Mean	1·4656	1157

Taking V = 1, $[v] = \cdot 7602$, $m = \cdot 0001567$

V expressed in actinometric degrees (B. 2.) = 44·35.

Faulhorn.

First Series.			Second Series.		
Hour.	Log v.	x.	Hour.	Log v.	x.
$7\frac{1}{2}$	1·2601	2197	10	1·5250	957
$8\frac{1}{4}$	1·3892	1501	11	1·5866	857
9	1·4639	1176	12	1·5717	827
3	1·4698	1178	1	1·5353	857
4	1·3802	1683	2	1·5224	958
$4\frac{1}{2}$	1·3304	2214			
Sum.	8·2936	9949	Sum.	7·7410	4456
Mean	1·3823	1658	Mean	1·5482	891

V = 1, $[v] = \cdot 6848$, $m = \cdot 0002163$

V expressed in actinometric degrees (B. 2.) = 55·07.

102. We thus find that when the *extreme* observations of each series are employed, the Faulhorn observations give a greater intensity to the extra-atmospheric radiation, and consequently a greater coefficient of extinction to the atmosphere, because the part of Curve XV. corresponding to the least thickness rises proportionably faster than the other part. But both results give greatly inferior extra-atmospheric radiation than the corrected hypothesis we have assumed; the first set gives 44°, the second 55°, the corrected hypothesis as much as 73° for the extra-atmospheric radiation.

103. If we avoid *extreme* columns and arrange the observations in alternating series so as to present a feeble but well-ascertained mean difference, we shall have results somewhat different, and more accordant at the two stations. These are contained in the following Tables, of which the first gives V = 42° nearly, the second 47° nearly, the difference being in the same direction as before.

Brientz.

First Series.			Second Series.		
Hour.	Log v.	x.	Hour.	Log. v.	x.
9	1·4065	1529	$8\frac{1}{4}$	1·3579	1952
11	1·4579	1113	10	1·4409	1244
1	1·5024	1111	12	1·4857	1073
3	1·3838	1529	2	1·4409	1242
$4\frac{1}{2}$	1·2095	2874	4	1·2989	2184
Sum.	6·9601	8156	Sum.	7·0243	7695
Mean. . . .	1·3920	1631	Mean. . . .	1·4049	1539

Taking V = 1, $[v] = \cdot 7827$, $m = \cdot 0001402$
V in actinometric degrees = 41°·75.

Faulhorn.

First Series.			Second Series.		
Hour.	Log v.	x.	Hour.	Log v.	x.
$8\frac{1}{4}$	1·3892	1501	$7\frac{1}{2}$	1·2601	2197
10	1·5250	957	9	1·4639	1176
12	1·5717	827	11	1·5866	857
2	1·5224	958	1	1·5353	857
4	1·3802	1683	3	1·4698	1178
			$4\frac{1}{2}$	1·3304	2214
Sum.	7·3885	5926	Sum.	8·6461	8479
Mean. . . .	1·4777	1185	Mean	1·4410	1413

Taking V = 1, $[v] = \cdot 7544$, $m = \cdot 0001609$
V in actinometric degrees = 46°·60.

104 Again, if we compare the *whole* observations at the Faulhorn in one series with the *whole* observations at Brientz in another, we find

	Mean value of log v.	Mean value of x.
Brientz	1·3984	1585
Faulhorn	1·4577	1310

from which we obtain,

taking V = 1, $[v] = \cdot 6857$,

agreeing (as might be expected) almost exactly with the result of Art. 69. p. 252, where the same quantity was deduced from the separate simultaneous observations. Also we have

$m = \cdot 0002156$
V in actinometric degrees = 54°·97.

Section VII.—*Other Observations in* 1832.

105. The following miscellaneous observations of the actinometer and other meteorological instruments were made simultaneously, or nearly so, at the Faulhorn by M. Kämtz, and at various inferior stations by myself in September 1832. If they afford no other immediate result, they at least show how unavailing such observations are unless made under the *most* favourable circumstances with respect to weather. I shall offer but few remarks upon these Tables, which after what has been said explain themselves sufficiently. I will add, however, that in point of care and continuity of observation, these observations are in general equally worthy of confidence with those of the 25th of September.

Table G.—Meteorological Observations at various Stations, September 1832.

Place.	Date.	Mean time.	Apparent time.	Barometer, French.	Attached Therm. Reaum.	Barometer in millimetres.	Attached therm. Cent.	Barometer at 0°.	Detached therm. Fahr.	Moist therm.	Diff.	Dryness. Elasticity of vapour.	Dryness. Relative Dampness.
	1832.	h m	h m	in. lin. 16ths.								inch.	
Near Grindelwald	September 16	9 6	9 14	24 4 13	9·4°	660·52	11·7	659·09	43·5°	40·0°	3·5°	·229	$\frac{229}{299}$ = ·766
Rosenlaui	September 16	12 15	12 23	24 2 10	12·6	655·61	15·7	653·69	46·5	39·4	7·1	·189	$\frac{189}{331}$ = ·571
Guttannen	September 17	12 20	12 28	25 1 4	13·2	679·57	16·5	677·57	64·2	56·0	8·2	·374	$\frac{374}{601}$ = ·622
Interlaken	September 22	10 44	10 52	26 8 14	14·2	723·85	17·7	721·49	67·0				
Interlaken	September 22	11 48	11 56	26 8 11	14·7	723·42	18·4	720·98	62·5	55·0	7·5	·360	$\frac{360}{587}$ = ·613
Grindelwald	September 23	11 15	11 23	25 2 7	10·2	682·25	12·7	680·65	59·0	52·5	6·5	·339	$\frac{339}{506}$ = ·670
Grindelwald	September 23	12 20	12 28	25 2 7	19·8	682·25	24·7	679·14	60·5	54·3	6·2	·368	$\frac{368}{532}$ = ·692
Giesbach............	September 24	3 5	3 13	26 6 0	17·0	717·35	21·2	714·53	68·0	61·5	6·5	·480	$\frac{480}{681}$ = ·705
Lungernsee	September 26	11 2	11 10	26 3 12	12·5	712·28	15·6	710·24	60·4	54·2	6·2	·365	$\frac{365}{530}$ = ·689
Near Sarnen	September 26	12 1	12 9	26 10 14	17·0	755·43	21·2	752·48	67·0	58·2	8·8	·395	$\frac{395}{659}$ = ·599

Table H.—Meteorological Observations on the Faulhorn, September 1832.

Place.	Date.	Mean time.	Apparent time.	Barometer, French, at 0° C.		Detached therm. Reaum.	Moist therm. Reaum.	Detached therm. Fahr.	Moist therm. Fahr.	Diff.	Elasticity of vapour.	Relative Dampness.
		h m	h m	lines.	mm.						inch.	
Faulhorn...	September 16	9 6	9 14	243·47	549·23	−6·0°	−6·5°	18·5°	17·4°	1·1°	·109	$\frac{109}{122}$ = ·893
Faulhorn...	September 16	11 21	11 29	243·79	549·95	−4·0	−5·2	23·0	20·3	2·7	·109	$\frac{109}{144}$ = ·757
Faulhorn...	September 17	12 20	12 27	245·51	553·83	+1·3	0·0	34·9	32·0	2·9	·175	$\frac{175}{221}$ = ·792
Faulhorn...	September 22	10 37	10 45	246·88	556·91	+3·0	+1·2	38·7	34·6	4·1	·185	$\frac{185}{253}$ = ·731
Faulhorn...	September 23	11 12	11 20	247·01	557·21	+3·4	+2·2	39·6	36·9	2·7	·209	$\frac{209}{261}$ = ·801
Faulhorn...	September 24	3 4	3 12	247·20	557·64	+3·8	+2·6	40·5	37·8	2·7	·222	$\frac{222}{269}$ = ·825
Faulhorn...	September 26	11 3	11 11	246·43	555·90	+6·1	+1·4	45·7	35·1	10·6	·134	$\frac{134}{322}$ = ·416
Faulhorn...	September 26	12 3	12 11	246·34	555·70	+5·4	+0·4	44·1	32·9	11·2	·112	$\frac{112}{305}$ = ·367

TABLE I.—Miscellaneous Actinometer Observations, September 1832.

Place.	Date.	Hour. From	Hour. To	Mean.	Apparent time.	Each observation.	Lower Station. Actinometer, G. 7.	Mean.	Reduced to 60 sec.	Reduced to B. 2.	Faulhorn. Hour. From	Faulhorn. Hour. To	Faulhorn. Mean.	Faulhorn. Apparent time.	Faulhorn. Actinometer. B. 2. each observation 60 sec.	Mean.
	1832.	h m	h m	h m	h m	s					h m	h m		h m		
Near Grindelwald..	Sept. 16.	8 56¾	9 6	9 1½	9 9	30	13·6; 13·2; 15·2; 15·2; 15·6; 15·2; 14·0	14·6	16·3	19·0	8 46	8 56	8 51	8 59	29·4; 29·4; 29·0; 29·7	29·4
Rosenlaui...........	Sept. 16.	11 49½	11 57	11 53¼	12 1	30	18·2; 22·3; 17·0; 19·4; 17·8	18·9	21·1	24·6	11 49½	11 57	11 53¼	12 1	39·8; 40·7; 38·9	39·8
Rosenlaui...........	Sept. 16.	11 56½	12 3½	12 0	12 8	30	20·3; 21·1; 20·4; 20·1; 18·5	20·1	22·4	26·2						
Rosenlaui...........	Sept. 16.	12 3	12 9½	12 6¼	12 14	30	18·4; 19·1; 19·2; 18·9; 19·7	19·1	21·3	24·9						
Guttannen.........	Sept. 17.	11 54	11 59½	11 56¾	12 5	30	18·9; 25·1; 28·9; 32·8	26·4	29·4	34·3	11 46	11 55½	11 50¾	11 59	48·0; 44·6; 43·6; 44·4	45·2
Guttannen.........	Sept. 17.	12 6½	12 15	12 10¾	12 19	30	25·3; 26·9; 27·5; 29·7; 27·1; 27·8; 27·8	27·4	30·5	35·6	12 10	12 19½	12 14¾	12 23	44·7; 43·9; 42·5; 43·0	43·5
Interlaken.........	Sept. 22.	10 44½	10 52½	10 48½	10 57	30	18·9; 19·3; 19·7; 21·1; 20·8; 20·8	20·1	22·4	26·2						
Interlaken.........	Sept. 22.	11 48½	11 55½	11 52	12 0	30	21·4; 22·7; 21·5; 21·6; 22·6; 24·0	22·3	24·8	29·0						
Interlaken.........	Sept. 22.	11 55	12 2½	11 58¾	12 7	30	20·1; 19·9, 20·0; 22·9; 24·0; 21·0	21·3	23·7	27·7						
Interlaken.........	Sept. 22.	12 2	12 9½	12 5¾	12 14	30	23·2; 23·9; 24·1; 27·1; 27·2; 26·4	25·3	28·2	32·9						
Grindelwald..	Sept. 23.	10 22½	10 28½	10 25½	10 34	30	17·0; 19·4; 17·0; 18·9; 17·2	17·9	19·9	23·2	10 27½	10 37	10 32¼	10 40	36·4; 36·9; 37·3; 36·5	36·8
Grindelwald........	Sept. 23.	10 28	10 35	10 31½	10 40	30	17·3; 18·2; 19·0; 19·9; 19·8	18·8	20·9	24·4	....	....	....	....	33·8; 34·0; 35·2; 36·7	34·9
Grindelwald........	Sept. 23.	10 53	11 8	11 0½	11 9	60	21·9; 22·5; 22·8; 23·5; 23·7; 24·1	23·1	....	27·0						
Grindelwald........	Sept. 23.	11 7½	11 14½	11 11	11 19	30	22·7; 23·0; 21·7; 24·0; 21·3; 22·0	22·4	25·0	29·2	11 12	11 21	11 16½	11 25	35·0; 34·3; 35·5; 36·0	35·2
Grindelwald........	Sept. 23.	11 40	11 45	11 42½	11 51	30	22·0; 22·7; 22·9; 23·9	22·9	25·5	29·8 } 31·2	11 39	11 48½	11 43¾	11 52	36·5; 35·1; 36·1; 37·8	36·4
Grindelwald........	Sept. 23.	11 44½	11 50	11 47¼	11 55	30	24·8; 24·9; 25·6; 24·9	25·0	27·8	32·5						
Grindelwald........	Sept. 23.	11 49½	12 5	11 52¼	12 0	60	25·4; 27·6; 27·0; 26·2; 25·8; 26·9	26·5	....	30·9						
Grindelwald........	Sept. 23.	12 6½	12 13	12 10	12 18	30	26·5; 27·2; 25·5; 25·9; 25·3; 23·6; 25·0	25·6	28·5	33·3						
Grindelwald........	Sept. 23.	12 12½	12 19½	12 16	12 24	30	25·2; 25·5; 23·6; 23·2; 23·9; 23·7	24·2	27·0	31·5						
Giesbach...........	Sept. 24.	3 5	3 10½	3 7¾	3 16	30	17·9; 15·8; 15·5; 16·6; 15·5	16·3	18·2	21·3	3 4	3 9	3 6½	3 15	31·1; 32·2	31·7
Giesbach...........	Sept. 24.	3 10	3 25½	3 17¾	3 26	60	16·9; 18·3; 18·8; 16·6; 18·0; 19·0; 19·2	18·1	....	21·1						
Lungernsee.........	Sept. 26.	11 2	11 20	11 11	11 19	60	22·7; 23·1; 23·9; 24·2; 24·9; 25·2; 24·7	24·1	....	28·1	11 3¼	11 29½	11 16¼	11 24	34·0; 34·3; 33·7; 35·2 34·5; 35·1; 33·7; 36·9 34·8; 36·0; 35·6; 35·2	34·9
Near Sarnen.......	Sept. 26.	12 1	12 12½	12 6¾	12 15	60	27·7; 26·2; 26·5; 27·7; 27·3	27·1	....	31·6 } 32·3	12 3	12 32¼	12 17½	12 26	40·6; 41·1; 40·9; 40·4; 41·2 40·9; 41·2; 41·4; 40·9 41·7; 40·8; 42·4; 42·2; 42·2	41·3
Near Sarnen.......	Sept. 26.	12 11½	12 21	12 16¼	12 24	60	28·7; 28·0; 28·1; 28·5	28·2	....	32·9						

TABLE K.—Miscellaneous Comparative Observations, September 1832.

No.	Date.	Hour*.	Position of Lower Station.	Lower Station. Barometer at 0° C.	Lower Station. Det. therm. FAHR.	Lower Station. Ratio to saturation.	Lower Station. Actinometer B 2.	Faulhorn. Barometer at 0° C.	Faulhorn. Det. therm. FAHR.	Faulhorn. Ratio to saturation.	Faulhorn. Actinometer B 2.	Diff. of Pressure.	Mean Temp.	Mean Dampness.	Loss of solar intensity.	Ratio of loss to effect at upper station.	Sun's altitude.	Barom. × Sec. Z. D. Lower Station.	Barom. × Sec. Z. D. Upper Station.	Barom. × Sec. Z. D. Diff.	Diff. × Mean Dampness.
	1832.	h m		mm.				mm.				m. m.			°		° ′				
1.	Sept. 16.	9 4	Near Grindelwald	659·09	43·5	·766	19·0	549·23	18·5	·893	29·4	109·86	31·0	·830	10·4	·354	31 54	1247·2	1039·3	207·9	172·6
				at 9h 14m																	
2.	Sept. 16.	12 1	Rosenlaui	653·69	46·5	·571	24·6	549·95	23·0	·757	39·8	103·74	34·7	·664	10·1	·254	45 54	910·3	765·8	144·5	96·0
				at 12h 23m	....	....	....	at 11h 29m													
3.	Sept. 17.	12 2	Guttannen	677·57	64·2	·622	34·3	553·83	34·9	·792	45·2	123·74	49·5	·707	10·9	·241	45 31	949·7	776·3	173·4	122·6
4.		12 21	....	at 12h 28m	....	....	35·6	....	....	....	43·5	......	....	....	7·9	·182	45 14				
5.	Sept. 22.	10 52	Interlaken	721·49	67·0																
				at 10h 52m																	
6.	Sept. 22.	11 56	Interlaken	720·98	62·5	·613															
7.	Sept. 23.	10 37	Grindelwald....	at 11h 56m	....	·655?	23·2	556·91	....	·731	36·8	124·76?	....	....	13·6	·369	39 42	......	871·9		
8.	Sept. 23.	11 22	Grindelwald....	680·65	59·0	·670	29·2	557·21	39·6	·801	35·2	123·44	49·3	·735	6·0	·170	42 24	1009·4	826·4	183·0	134·5
9.	Sept. 23.	11 52	....	at 11h 23m	....	·680	31·2	at 11h 20m	....	....	36·4	......	...	...	5·2	·143	43 8				
10.	Sept. 23.	12 28	Grindelwald....	679·14	60·5	·692															
				at 12h 28m																	
11.	Sept. 24.	3 15	Giesbach	714·53	68·0	·705	21·3	557·64	40·5	·825	31·7	156·89	54·2	·765	10·4	·328	26 35	1596·7	1246·1	350·6	268·2
				at 3h 13m																	
12.	Sept. 26.	11 21	Lungern See ..	710·24	60·4	·689	28·1	555·90	45·7	·416	34·9	154·34	53·0	·558	6·8	·195	41 15	1075·2	841·6	233·6	130·3
				at 11h 10m																	
13.	Sept. 26.	12 23	Near Sarnen ..	752·48	67·0	·599	32·3	555·70	44·1	·367	41·3	196·78	55·5	·483	9·0	·218	41 46	1129·7	834·3	295·4	142·7
				at 12h 29m	....	....	....	at 12h 11m													

* The hour here is the mean apparent time of the actinometer observations at both stations.

Remarks at the *Lower* Station.

No.
1. Hasty observations. Very clear.
2. Sky quite clear, except some passing well-defined clouds, which were avoided.
3. Very fine sky.
5. Sky quite cloudless, but not a fine blue. Observations at the window of the inn.
7. Magnificent sky. Observations at the window of the inn.
11. Quite clear. Not a cloud all day.
12. Splendid sky. A little wind.

Remarks at the *Upper* Station by M. KÄMTZ.

No.
1. Fog in the valley of Grindelwald from $9\frac{1}{2}$ to 10^h.
2. Fogs some time passing. Observations made in the intervals when none near the sun.
3. This observation and the preceding ones were made in a room. The following ones were out of doors.
8. Clouds on the Schreckhorn and northern plain.
9. After this clouds sometimes pass through the zenith and before the sun.
11. Some fogs.

Curves XXI. and XXII. Plate XXV. show the relative march of the actinometer at Grindelwald and the Faulhorn on the 23rd of September, during the latter part of which clouds appeared at the upper station which were not visible, or at least not observed, at the lower; and the effect on the inflection of the diurnal curve is the same as that noticed Art. 79, p. 255.

106. Although these observations were never made except when the sun appeared to shine through a clear blue sky, the rate of extinction is enormously greater than in the formerly described more favourable circumstances. By selecting the observations directly comparable, and reducing them as in Art. 62, I have found an absorption equal to *three-fourths* of the incident heat, the mean ratio to saturation being ·6717. But it must be confessed that no evident relation to the hygrometric condition of the air appears in the individual observations.

Section VIII.—*Observations in* 1841.

107. These were made under very far from favourable circumstances at one station only, namely, on the lower glacier of the Aar, at an elevation of about 7000 feet above the sea. Although the sky was to appearance generally clear and of a deep blue during the continuance of these observations, the occasional formation of slight clouds, and the feeble degree of dryness, considering the elevation, explains the comparatively great opacity of the atmosphere which we deduce from these observations. The instrument was a different one and partly on a different construction from those formerly used, and they have not been compared, consequently the actinometric degrees are not convertible into one another. It may be doubted whether the surface of a glacier is not a very bad position for such observations, owing to the stratum of moist air, which in summer must generally rest upon it during the heat of the day, and the glare from the adjoining mountains is an evil not wholly to be avoided. I must state, however, that numerous comparative experiments which I made on this occasion with the actinometer and with Leslie's photometer, convinced me of the remarkable constancy and truth of the indications of the former. My immediate object was to verify a conjecture which I had published* respecting an anomaly in solar radiation described by Dr. Richardson in the arctic regions, as measured by the statical thermometric effect. The anomaly was that the maximum occurred in April or May, instead of in June or July, as elsewhere; and the explanation I gave was that the disappearance of the snow from the earth's surface in the month of May diminished the solar effect more than the sun's greater elevation increased it. This was confirmed by finding the *enormous* indications given by Leslie's photometer on the glacier of the Aar, at a time when the sun's rays were not peculiarly intense, which I ascribed to the glittering reflection from the surface of the glacier, and from the amphitheatre of snowy mountains. When the instrument was placed on a rock, or merely on a piece of black wax-cloth laid upon the snow, it sunk in a very remarkable manner. The actinometer, on the other hand, when supported on a small box, so as just to avoid contact with the snow, gave appreciably the same result in both situations.

108. The following are the most available meteorological observations made in 1841 :

* Jameson's Edinburgh New Philosophical Journal for 1841.

COMPARATIVE INTENSITY OF SOLAR RADIATION.

GRINDELWALD & FAULHORN _ SEPT^R. 23^RD. 1832.

Phil. Trans. MDCCCXLII. Plate XXV. p. 268.

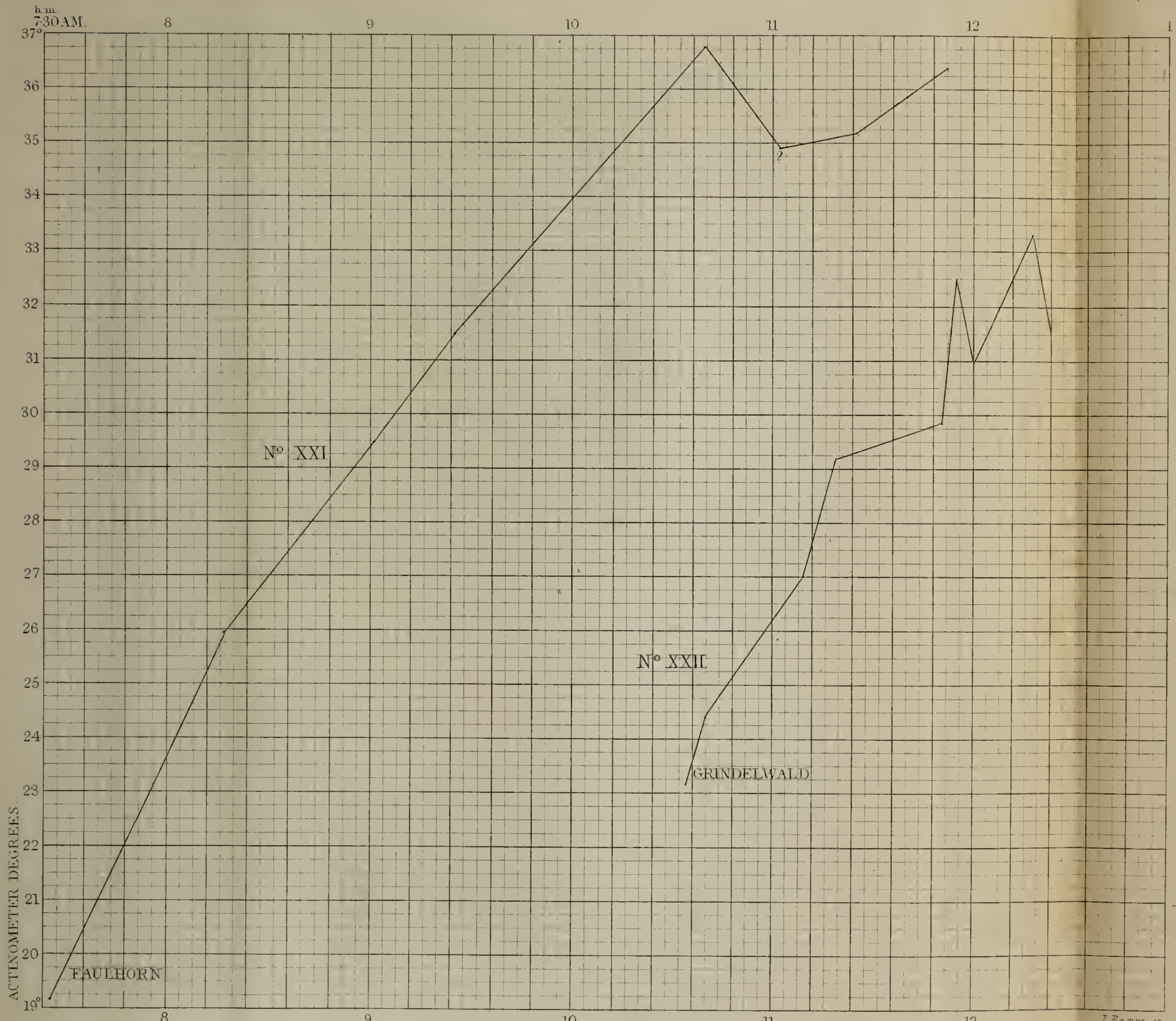


TABLE L.—Observations on the Lower Aar Glacier, 13th and 14th August 1841.

Mean height on the Barometer 568^{mm}. Latitude 46° 33′ N.

1841.	Hour. From	Hour. To	Hour. Mean.	Thermometer. Dry. Reaum.	Thermometer. Moist. Reaum.	Thermometer. Dry. Fahr.	Thermometer. Moist. Fahr.	Diff. Fahr.	Elasticity of vapour.	Relative dampness.	Actinometer S. 1. Each observation 60 seconds.	Mean.	Sun's altitude.	Thickness of atmosphere = Bar. × sec. Z. D.	Remarks.
	h m	h m	h m										° ′	mm.	
Aug. 13.	6 41	6 52	6 46	......	......	......	......	......	......	......	6·2; 8·0; 9·3; 10·1; 10·6	8·84	19 29	1703·0	Aug. 13. Light clouds generally visible in some part of the sky, but not so as to conceal the sun at any time.
	7 57	8 11½	8 4	......	......	......	......	......	......	......	10·2; 12·5; 14·8; 17·0; 15·5; 14·9	14·15	31 51	1076·4	
	9 0	9 11½	9 6	1·8	− 1·2	36·0	29·3	6·7	·124	$\frac{124}{230}$ = ·539	18·4; 15·8; 16·4; 20·0; 21·8	18·5	41 55	850·2	
	10 0	10 13½	10 7	4·9	+ 2·0	43·0	36·5	6·5	·178	$\frac{178}{293}$ = ·607	24·7; 20·8; 21·3; 21·5; 20·6; 23·1	22·0	50 28	736·5	
	12 0	12 16	12 8	5·9 at 12^h 30^m	+ 2·6	45·2	37·8	7·4	·182	$\frac{182}{317}$ = ·574	25·9; 27·2; 26·9; 27·8; 28·4; 26·0	27·03	58 8	668·8	
	2 44	2 59½	2 52	5·4	+ 3·1	44·1	38·9	5·2	·209	$\frac{209}{305}$ = ·685	20·7; 20·5; 22·0; 20·7; 29·0	22·58	41 53	850·8	
	4 0	4 9½	4 5	5·0	+ 2·5	43·2	37·6	5·6	·195	$\frac{195}{296}$ = ·659	21·6; 23·1; 23·1; 20·3	22·02	30 15	1127·5	
	5 7	5 17¼	5 12	......	......	......	......	......	......	......	20·0; 19·3; 20·5; 20·1	20·0	18 45	1767·0	
Aug. 14.	6 18	6 27	6 22½	1·8	− 0·2	36·0	31·6	4·4	·159	$\frac{159}{230}$ = ·691	8·4; 8·55; 9·3; 10·5	9·19	15 52	2077·5	
	8 51½	9 10¼	9 1	7·7 at 10^h 30^m	+ 3·0	49·3	38·7	10·6	·162	$\frac{162}{365}$ = ·444	15·7; 16·95; 20·25; 21·6; 23·3; 19·2; 22·95; 22·55	20·3	40 51	868·4	
	11 55	12 13	12 4	6·7	+ 3·0	47·1	38·7	8·4	·181	$\frac{181}{338}$ = ·536	21·1; 23·9; 23·2; 23·3; 23·8; 25·1	23·4	57 46	671·5	
	12 22¼	12 31¼	12 27	6·6	+ 3·0	46·8	38·7	8·1	·184	$\frac{184}{335}$ = ·549	25·4; 26·3; 26·7; 26·5	26·22	57 18	675·0	A few vapours, very light, appear. Wind rises.

109. If we compare the longest with the shortest columns on the 13th of August, we obtain in the notation of Art. 100., taking $V = 1$, $[v] = \cdot 6403$, $m = \cdot 0002549$.

V in degrees of actinometer S. 1. $= 35^{\circ}\cdot 22$.

And on the 14th of August, $[v] = \cdot 5680$, $m = \cdot 0003232$.

V in degrees of actinometer S. 1. $= 40^{\circ}\cdot 87$.

110. These results are on the logarithmic hypothesis. If, however, we project the observations, as we have done those of the 25th of September, 1832, we find that they cannot be represented by a simple geometrical progression. An interpolating curve, which will satisfy them sufficiently well, is a logarithmic curve, whose asymptote is distant $7^{\circ}\cdot 25$ actinometric degrees from the axis of x. The curve is represented in Plate XXVI. Curve XXIII. The constants of the curve were derived by a graphical process, as in the former case, tangents having been first drawn to the empirical curve, whence the following velocities of extinction were deduced, which are compared with a formula of the same form as in Art. (93.), namely

$$-\frac{d\,v}{d\,x} = a\,v - b.$$

The values of a and b were deduced from the projection, Curve XXIV. in the same Plate, which gives $7^{\circ}\cdot 25$ for the intensity when the rate of extinction is zero; and

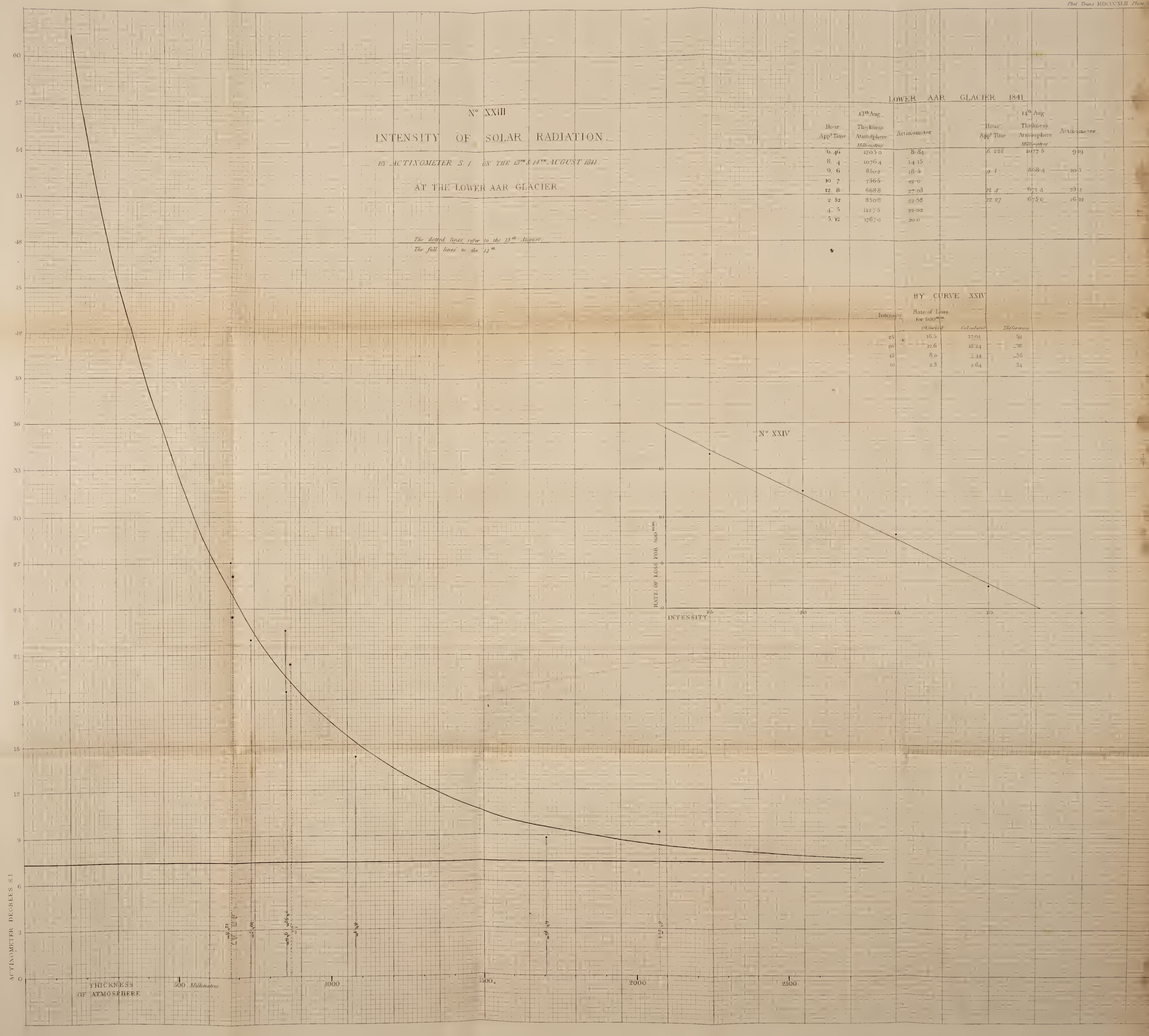
$$\left.\begin{array}{l} a = \cdot 00192 \\ b = \cdot 01396 \end{array}\right\} \text{for } 1^{\text{mm}} \text{ of thickness.}$$

Intensity.	Rate of loss for 500 millimetres. Observed.	Calculation.	Difference.
25	16·5	17·04	+0·54
20	12·6	12·24	−0·36
15	8·0	7·44	−0·56
10	2·3	2·64	+0·34

Whence the following points of the curve have been computed from forms similar to those of Art. 96, $\frac{b}{a}$ being here 7·25.

Thickness, or x in millimetres of mercury.	Intensity, or degrees of Actinometer S. I.
0	70·74 + 7·25 = 77·99
500	25·51 + 7·25 = 32·76
1000	9·20 + 7·25 = 16·45
1500	3·32 + 7·25 = 10·57
2000	1·20 + 7·25 = 8·45
2500	0·43 + 7·25 = 7·68

111. Hence it appears that a general analogy holds with results of the 25th of September 1832. It is even not improbable that the degrees of the two instruments do not greatly differ in value, and that the lower indications in 1841 are due solely to the greater opacity of the air, marked by the rapid decline of the curve, and (as might be anticipated) the lower value of the limiting or final intensity.



LOWER AAR GLACIER 1841

13th Aug. Hour Appt Time	Thickness Atmosphere Millimetres	Actinometer	14th Aug. Hour Appt Time	Thickness Atmosphere Millimetres	Actinometer
6. 46	1703·0	8·84	6. 22½	2077·5	9·9
8. 4	1076·4	14·15			
9. 6	850·2	18·5	9. 7	868·4	20·3
10. 7	736·5	22·0			
12. 8	668·8	27·03	12. 4	671·4	23·1
2. 52	850·8	22·58	12. 27	675·0	26·22
4. 5	1127·5	22·02			
5. 12	1767·0	20·0			

BY CURVE XXIV

Intensity	Rate of Loss for 500mm Observed	Calculated	Differences
25	16.5	17.04	.54
20	12.6	12.24	–.36
15	8.0	7.44	–.56
10	2.3	2.64	.34

Section IX.—*Conclusions.*

112. On the whole, it appears from the facts and reasonings of this paper,—

1. That the absorption of the solar rays by the strata of air to which we have immediate access, is considerable in amount for even moderate thicknesses.

2. That the diurnal curve of solar intensity has, even in its most normal state, several inflections, and that its character depends materially upon the elevation of the point of observation.

3. That the approximations to the value of extra atmospheric solar radiation, on the hypothesis of a geometrical diminution of intensity, are inaccurate.

113. The coincidence found by M. Pouillet (Art. 22.) between the logarithms of the intensities and the thicknesses, may be ascribed to his having used a formula which gives the *greater* thicknesses sensibly too small, and thus makes an accidental compensation. Perhaps another accidental compensation may be found in the continuity of the Curve XV. I have mentioned (Art. 82.) that I expected to find a different law for extinction in the higher and lower regions of the atmosphere. It may be that the greater purity of the air in the higher regions, and its great dryness, counterbalance the greater absorptive power which we have attributed (Art. 85.) to the first portions of an absorbing medium traversed by light or heat.

114. We further conclude,—

4. That the tendency to absorption through increasing thicknesses of air is a diminishing one. That in fact the absorption almost certainly reaches a limit, beyond which no further loss will take place by an increased thickness of similar atmospheric ingredients. That the residual heat (tested by the absorption into a blue liquor) may amount to from a half to a third of that which reaches the surface of the globe after a vertical transmission through a clear atmosphere.

5. That the law of absorption in a clear and dry atmosphere, equivalent to between one and four times the mass of air traversed vertically, may be represented (within those limits) by an intensity diminishing in a geometrical progression, *plus* a constant quantity, which is the limiting value already mentioned. Hence the amount of vertical transmission has always hitherto been greatly overrated, or the value of extra atmospheric solar radiation greatly underrated.

6. The value of extra atmospheric solar radiation upon the hypothesis of the above law being generally true, is 73° of the actinometer marked B. 2. The limiting value of the solar radiation, after passing through an *indefinite* atmospheric thickness, is 15°·2.

7. The absorption in passing through a vertical atmosphere of 760 millimetres of mercury, is such as to reduce the incident heat from 1 to ·534.

8. The physical cause of this law of absorption appears to be the non-homogeneity of the incident rays of heat; which by parting with their more absorbable elements become continually more persistent in their character, as Lambert and others have shown to take place where plates of glass are interposed between a source of heat and a thermometer.

9. Treating the observations on BOUGUER's hypothesis of an *uniform ratio* of extinction to the intensity of the incident ray, we obtain for the value of the vertically transmitted share of solar heat in the entire atmosphere:—

By the *relative* intensities at Brientz and the Faulhorn, Art. 69. . .	·6842
By the observations at the Faulhorn alone, 1st method, Art. 101. .	·6848
By the observations at the Faulhorn alone, 2nd method, Art. 103. .	·7544
By the observations at Brientz alone, 1st method, Art. 101. . . .	·7602
By the observations at Brientz alone, 2nd method, Art. 103. . .	·7827

ADDITIONAL NOTES.

NOTE A.—*On the Absolute Values of the Degrees of the Actinometers employed.*

Since writing this paper Sir JOHN HERSCHEL, to whom I submitted the results, has favoured me with the following information:—

"It happens very fortunately that as regards actinometer G, No. 7, I find a series of direct comparisons of this with my standard H, No. 8, which is that I employed to determine the parts of its scale in *actines*" [see Art. 19. of this paper]. "The series in question was made March 15, 1828, and gave the results of alternate sets as follows:—

G. 7.	H. 8.
20°·8	21·3
21·5	21·6
20·7	21·2
20·75	21·0
20·65	19·9
20·9	21·0
	Rejecting the last 21·3

Whence it results that the same radiation which raises G. by 209 parts would raise H. by 213 parts; or 1 part of G. 7. is equivalent to $\frac{213}{209} = 1{\cdot}019$ parts of H. 8.

"Now the value of 1° of the scale of H. 8. I ascertained by an elaborate series of experiments under a sun as nearly vertical as the Cape latitude would allow, and in eminently favourable circumstances, to be 6·093 actines; so that one part of G. 7. is equivalent to 6·209 actines."

In the preceding paper the indications of G. 7. have been reduced to those of B. 2. Assumed as a standard, it has been found (Art. 54.) that the factor of reduction for the readings of G. 7. to those of B. 2. is 1·168. Hence to invert the process or reduce B. 2. to G. 7. we must multiply by

$$\frac{1}{1{\cdot}168} = 0{\cdot}856;$$

and to reduce the readings of B. 2. into "actines" we have the factor $0{\cdot}856 \times 6{\cdot}209 = 5{\cdot}315$.

The scale of "actines" has been added to the margin of the Curve XV. Plate XXII.

Intensity of extra-atmospheric radiation,

$73^{\circ}{\cdot}06$ B. 2. (Article 97.) = 388·4 actines.

After vertical transmission through the atmosphere,

$39^{\circ}{\cdot}03$ B. 2. = 207·4 actines.

Residual intensity after an indefinite transmission,

15·2 B. 2. = 80·8 actines.

Note B.—*On Article* 48.

I have certainly not exaggerated here the difficulties in respect of weather. During the summer which has passed since the reading of this paper (1842), I have sedulously sought the opportunity of making some additional actinometer observations amongst the Alps, under the most favourable circumstances. But though the season was, as every one knows, more than commonly fine, I did not succeed in getting a single series of observations worth preserving, of the kind which I required. Excepting about three days in the end of June, and perhaps as many in the middle of August, the whole summer presented no unexceptionable weather, and on these two occasions I was unavoidably prevented from making use of my instruments, of which I had taken two from England on purpose. One experiment which I desired to make was, to push the observations to still greater thinness of atmosphere than could be obtained at the Faulhorn so late as the month of September, and for this purpose I proposed to ascend the Cramont (8966 feet) soon after the summer solstice, and I actually did spend a whole day without result on the summit in the month of July. By making single observations throughout the greater part of a day, I proposed to push the experimental Curve XV. further than had yet been done.

I also proposed another experiment which I recommend to future observers. I coated the bulb of one actinometer with white paint. The comparative value of the scale of this and another naked or dark blue bulb, would depend upon the nature of the incident heat (see Art. 3.). With heat from terrestrial sources transmitted by *most* diathermanous bodies, the *colour* of the surface becomes more and more influential, as the heat has been drained of its more absorbable part. But it would be very interesting to verify the fact in the case of the solar rays passing through air. For this purpose I proposed to compare the white and the dark actinometers at the top and at the bottom of a high mountain such as the Cramont, and I expected to find the disproportion least above and greatest below.

XV. *Contributions to the Chemical History of Palladium and Platinum.*

By ROBERT KANE, *M.D., M.R.I.A.* *Communicated by* FRANCIS BAILY, *Esq., V.P.R.S., &c. &c. &c.*

Received February 24,—Read March 17, 1842.

NOTWITHSTANDING the attention which has been paid to the properties of the noble metals by the chemists who have made their compounds an object of study, their history is yet very far from the state of completeness, to which so many departments of inorganic chemistry have recently been brought. The researches hitherto made have had for their objects generally, either the more direct or certain extraction of the metal from the state of combination in which it naturally exists, or the examination of some few compounds, which were remarkable for their beauty or facility of production, or important from their applications. But the general history of these metals has as yet been but imperfectly studied, as may be seen by reference to the meagre account of their salts and other compounds, which even the most extended systematic works present. It is my object in this and in some subsequent papers, to examine specially into the composition and properties of the compounds of palladium, platinum, and gold, and to endeavour to ascertain how far they agree, and in what they differ, as to the laws of combination to which these compounds are subjected. As this paper may be considered but as the commencement of this work, the general bearings of which may change according to the progress of our knowledge, I shall not attempt to give to it any systematic form, or to arrange the bodies to be described in any order or classification, except that all the compounds of the same metal will in each memoir be described together.

It is my duty, at this moment, to express my sincere gratitude and thanks to the Council of the Royal Society, which most kindly placed in my hands, for the purposes of these investigations, a portion of the palladium that had been bequeathed to the Society by its illustrious discoverer, to be used in the advancement of science. Should the results I have obtained, in endeavouring to extend and render more accurate our knowledge of the compounds of that remarkable metal, appear such as to justify that appropriation, for which when made I feel I had little claim, I shall be fully rewarded for the time and labour they have required, and use my best efforts to extend them by subsequent researches.

Section I.—Palladium Compounds.

Oxides of Palladium.

It has been long established that palladium combines with oxygen, at least in two proportions, forming the *protoxide*, which is the basis of its ordinary salts, and the *deutoxide*, which appears to be analogous to the deutoxide of platinum, and to react in many cases as an acid. To this last body I have not hitherto directed much attention, but some properties of the protoxide which I have noticed appear not unworthy of being described.

The protoxide of palladium is best prepared by the decomposition of the protochloride, by means of a solution of carbonate of soda in excess. The precipitate which first forms is light-coloured, but it soon becomes darker, carbonic acid gas is disengaged, and finally an ochrey brown powder falls, which, by drying, becomes dark brown. The precipitation is in this case by no means perfect, the liquor is coloured yellow by traces of the metal dissolved, and the precipitate retains with obstinacy traces of the alkali, from which, however, it may be freed by washing.

When this substance is heated, it first evolves water and then oxygen, leaving a black powder, to the nature of which I shall recur. By a very high temperature (full white heat) it is totally reduced to the metallic state.

The analyses of this hydrated oxide when first performed led to very irreconcileable results, owing to two circumstances,—1st, that the oxide of palladium is by no means so easily reduced to the metallic state by the mere agency of heat as has been supposed; and 2nd, that although the precipitation of the hydrated oxide is accompanied with the disengagement of much carbonic acid, yet the precipitate always contains some traces of that acid; it effervesces very distinctly when dissolved in dilute muriatic acid, and is in fact a highly basic carbonate of palladium, rather than a true hydrated protoxide. The following details of the experiments made as to its composition, will place these circumstances in evidence.

A. 53·524 grains of a specimen which had been carefully washed until the liquors ceased to react alkaline, were gently heated over the flame of a spirit-lamp, until no more traces of water were evolved. The residue, a jet black powder, of anhydrous oxide, weighed 45·224 grains, or 84·49 per cent., having lost 15·51, apparently only water.

B. 41·102 grains of another portion, similarly treated, gave a dry residue of 34·512 grains, or 83·96 per cent. This was then heated to full redness, and when cold weighed 31·779 grains, or 77·32 per cent.

C. 72·481 grains of a specimen prepared at another time gave, when dried until the last traces of water had been driven off, a black powder weighing 61·241 grains, or 84·49 per cent., and at exposure to a red heat was reduced to 56·131 grains, or 77·45 per cent.

D. 56·578 grains of a different specimen gave when dried 48·306 grains, or 85·38

per cent., having lost 14·62 of water. By a red heat it gave off oxygen, and was reduced to 44·846 grains, or 79·43 per cent.

These results placed together for comparison give,—

	A.	B.	C.	D.
Expelled by a moderate heat . .	15·51	16·04	15·51	14·62
Expelled by a red heat	84·49	6·64	7·04	5·95
Residual black powder		77·32	77·45	79·43

The material (6 to 7 per cent.) expelled by a red heat is oxygen gas, but I found, by trials conducted after the above results were obtained, that neither is all the material expelled by a moderate heat merely water, nor is the residual black powder metallic palladium.

E. To determine the nature of the black powder which remains after the moderate ignition of the oxide, 51·346 grains of it were introduced into a tube of Bohemian glass, and heated in a current of dry hydrogen gas; it became of itself brightly red-hot, water was abundantly, almost explosively formed, and the powder assumed at once a gray metallic aspect. It then weighed 47·165 grains, or 91·85 per cent.

F. To control this result another portion of the black powder, obtained from a different portion of oxide, was heated in the same way in hydrogen gas. From 46·300 grains there remained 42·952 grains of metal, or 92·72 per cent.

The quantity of oxygen thus shown to be combined with the metal in this black powder is almost exactly half that which the protoxide should contain. It must therefore be considered as *suboxide of palladium*, at least provided it be not a mixture of metal and protoxide, which shall be discussed further on. I shall here only compare the experimental results with those given by the formula Pd_2 Cl for its composition.

	Theory.		Experiment.	
Pd_2 =	106·6	93·02	91·85	92·72
O =	8·0	6·98	8·15	7·28
	114·6	100·00	100·00	100·00

The mean quantity of black suboxide obtained by the moderate ignition of the hydrated oxide as already found, is 78·07, and this is shown by the latter experiments to contain 72·60 of metal; excluding therefore for the moment, the question whether anything but water is first driven off, we find that the oxide of palladium may be obtained anhydrous, that by gentle ignition it abandons one-half of its oxygen and leaves a black powder, *suboxide*, which may be totally reduced to the metallic state by violent ignition or by hydrogen gas, at incipient redness.

The mean quantity of suboxide furnished from 100 of dry protoxide, in the above described three analyses, may be thus compared with theory:—

	Theory.		Experiment.—Mean of B, C, D.	
Pd_2O =	114·6	93·47	78·07	92·27
O =	8·0	6·53	6·54	7·73
	122·6	100·00	84·61	100·00

The analysis D alone gives a result much more closely approximating to theory: by it there is

Pd_2O	79·43,	or	93·03
O	5·95,	or	6·97
	85·38		100·00

As there were many circumstances which led me to consider it unlikely that the 15·42, the mean quantity of material expelled from the hydrated oxide by a moderate heat, could be entirely water, I determined the real quantity of water present in the following manner. The substance was placed in a tube of Bohemian glass, which at one end was put in connection with an apparatus evolving dry hydrogen gas, and at the other extremity was adapted to a tube containing recently fused chloride of calcium. When the apparatus had been completely filled with hydrogen, the tube containing the oxide of palladium was heated by means of charcoal. Water was evolved and the metal reduced. The current of gas was continued until all water had been carried into the chloride of calcium tube, and the weights were then determined. It was found that from 45·687 grains of the hydrated oxide, there were obtained 33·532 grains of metal, and 11·298 grains of water, giving 73·95 for the former, and 24·74 for the latter per cent., but of this 24·74, there were formed 12·49 by means of 11·10 of oxygen which had been combined with the metal, and the water of hydration amounted therefore to but 12·25 per cent.

The difference between the total volatile matter and the water (3·17 per cent.), may be certainly considered as carbonic acid, from the circumstances under which the substance is prepared, and from the fact that it in all cases effervesces slightly when dissolved in muriatic acid.

We may sum up, therefore, the composition of this true basic carbonate of palladium as follows:—

	Last Experiment.	Mean of A, B, C, D.
Palladium . .	73·95	72·60
Oxygen . . .	10·63	11·98
Water	12·25	15·42
Carbonic acid .	3·17	
	100·00	100·00

The formula deducible from these results is $10.PdO + CO_2 + 10.HO$, which gives the following numerical result:—

Ten atoms of palladium	533·0	73·52
Ten atoms of oxygen	80·0	11·04
Ten atoms of water	90·0	12·41
One atom of carbonic acid . . .	22·0	3·03
	725·0	100·00

It is not impossible but this body may be in reality a mixture of a less basic carbonate, with the true hydrated oxide, but I consider that the remarkable constancy of composition, indicated by so many specimens, prepared at different times, giving results so closely coinciding, argues very strongly in favour of its definite nature. It occurred to me also that the content in carbonic acid might arise from the presence of carbonate of soda, but I satisfied myself that although it is very difficult to obtain specimens which do not after ignition yield traces of alkali, yet it is never present in such quantity as could give the above results, when the freshly precipitated substance has been properly washed.

The properties of the suboxide of palladium, now first definitely found, are not very distinct. The existence of this suboxide had been long suspected, especially from the fact, that by heating to dull redness in contact with air, metallic palladium becomes coloured blue or green on the surface, which colours are removed by violent ignition. Berzelius found, however, that this colouring was not attended with any increase of weight, which arises, however, from the minute quantity of oxide formed, the colours being those of thin plates ; but there can be now no doubt but that formation of suboxide does so occur. That the black powder which is left by the dull ignition of the basic carbonate is really a definite compound, is strongly supported by the fact of the accuracy with which the decomposition stops at its formation, and by the analogy of the subchloride, to be hereafter described, it gains additional force. Yet I have not been able to combine in any way this suboxide with acids. By contact with them, it gives an ordinary salt of the protoxide and metal. It is possible, however, that in future trials I may be more successful.

It is known that by the addition of a caustic fixed alkali to a salt of palladium a precipitate is obtained, which redissolves in a great excess of the alkali. The precipitate is in this case a basic salt, not the hydrated oxide, and always contains traces of the alkali, from which it is with difficulty freed by washing. The soluble alkaline compound cannot be obtained in a definite form by any process that I have as yet tried. By evaporation to dryness, the oxide separates anhydrous, and retaining a small quantity of alkali.

When the basic carbonate of palladium (hydrated oxide) is diffused through water of ammonia, it partially dissolves, giving a brown powder and a yellow-coloured liquor, which when evaporated dries down to a bright yellow deliquescent mass. When heated, this decomposes with slight deflagration and copious disengagement of gas, leaving metallic palladium. The brown powder also contains ammonia, and when heated gives it off with water, and the metal is reduced. I can, however, at present only indicate the existence of these two bodies, as the analytical results which I have obtained respecting them are too discordant to admit of my assigning any definite formulæ for their constitution. The soluble compound I conceive to arise from the ammonia acting on the carbonate, as it does on any other palladium salt, and the insoluble to be the product of the ammonia on the oxide which is present in excess. I reserve these bodies, therefore, as objects of future study.

Chlorides of Palladium.

The properties of the ordinary protochloride of palladium have been for the most part so fully described by those chemists that have previously occupied themselves with the study of this metal, that I shall notice it but briefly. From a strong solution, it crystallizes in prismatic needles which are very deliquescent. These crystals were found to contain two atoms of water of crystallization, which they lose by a gentle heat.

The action of a high temperature on protochloride of palladium developes some facts of considerable interest. It is not so reduced to the metallic state unless by very violent ignition, but just at a red heat it melts and begins to evolve chlorine, which continues until it has parted with one-half of that which it contains. The liquefied mass which remains is a true subchloride, which is not further acted upon, unless the heat be very much increased.

The following numerical results will render this decomposition evident:—

A. 29·881 grains of the crystallized protochloride being carefully dried as long as they gave off any traces of watery vapour were found to have lost 5·247 grains, or 17·56 per cent.

The dried mass was heated until it had completely fused. It was then dull red. In this state it was found to weigh 22·055 grains, having given off 2·577 grains of chlorine, or 8·63 per cent.

This was next kept melted at a bright red heat until it appeared to cease giving off any gas. It then weighed 19·632 grains, having lost in addition 2·423 grains, or 8·11 per cent. of chlorine.

This residue was now fully ignited with some carbonate of ammonia, until the metallic palladium remaining appeared to be quite pure; this then weighed 14·554 grains, or 48·71 per cent., the quantity of chlorine abandoned in this final stage having been 5·078 grains, or 16·99 per cent.

The quantity of palladium and the total quantity of chlorine and water, show that the salt in its crystalline condition has the formula Pd Cl + 2 H O, by which we have

	Theory.		Experiment.
Palladium . .	53·3	49·95	48·71
Chlorine . .	35·4	33·18	33·73
Water . . .	18·0	16·87	17·56
	106·7	100·00	100·00

The relation between the proportions of chlorine which were evolved at the different periods, were as 8·11, 8·63, and 16·99. I do not attach much importance to the two first being so nearly equal, but to the fact that the quantity which was not expelled by the heat was sensibly equal to half the total quantity in the salt.

B. 58·919 grains of dried protochloride were heated in a porcelain crucible to full redness, until it fused without any disengagement of gas. The residual subchloride weighed 47·782 grains, or 81·13 per cent.

C. 138·397 grains were fused in a porcelain crucible and kept at a full red heat until all effervescence from loss of chlorine ceased. When cold it weighed 110·185 grains, equivalent to 80·41 per cent.

These results fully prove that the loss of chlorine which the protochloride undergoes when kept for some time fused at a full red heat, is perfectly definite; and also that the loss represents one-half of the chlorine which the salt contains. Thus,

$$\begin{array}{rrlr} \text{by theory } Pd_2 = & 106·6 & \text{produce } Pd_2 = & 106·6 \\ Cl_2 = & 70·8 & \text{produce } Cl \;\; = & 35·4 \\ \hline & 177·4 & & 142·0 \end{array}$$

or 80·05 per cent. The substance formed is a true subchloride analogous to calomel, or to subchloride of copper, and its formula is $Pd_2\ Cl$.

The fused mass obtained by the methods now described, is of a deep red brown colour, and highly crystalline in structure. Its powder is light red. It deliquesces rapidly, and becomes dark-coloured from the separation of metallic palladium and the formation of protochloride. This change is effected almost instantly by contact with water, or solutions of sal-ammoniac, or iodide of potassium, also by water of ammonia. It is, however, not all decomposed; the quantity of metallic palladium which separates, I have found to be but from one-fifth to one-sixth of that which the subchloride contained. The liquor formed contains, therefore, both the subchloride and the protochloride dissolved together. The action of reagents on this liquor, however, does not differ materially from that produced with solutions of the protochloride. The liquor is much darker coloured than a solution of protochloride of the same strength should be, and is rendered turbid by dilution with more water. The first action of ammonia appears to be, the formation of a white compound, which is however almost instantly broken up into the pinkish ammonia-protochloride, and metallic palladium.

In the double salts formed by the protochloride of palladium with the chlorides of the alkaline metals, I have found the similarity of constitution so usual between the compounds of ammonium and potassium to be violated. The double chloride of palladium and potassium has been fully shown by Berzelius to have the formula $Pd\,.\,Cl + K\,.\,Cl$, and not to contain any water of crystallization; but the double chloride of palladium and ammonium retains an atom of water when crystallized. I examined a quantity of this salt which had formed long rectangular prisms of an olive colour with a rich bronze lustre. They were quite free from any foreign impurities. When heated, they yielded water, muriatic acid, sal-ammoniac, and left metallic palladium.

By a very cautious application of heat the water may be completely expelled. From many experiments its quantity was found to be from 5·52 to 5·95 per cent.,

and the residual palladium was ascertained to be from 35·56 to 35·27 in 100 of the crystals. These numbers indicate the formula $Pd\,Cl + N\,H_4.Cl + H\,O$, which gives

Pd	$= 53·3$	35·28
Cl_2	$= 70·8$	46·86
$N\,H_4$	$= 18·0$	11·91
	$= 9·0$	5·95
	151·1	100·00

If the salt were anhydrous it should yield 37·51 per cent. of metal.

It is only in consequence of its differing from the potassium salt that I deem this body worthy of notice here.

Of the Oxychloride of Palladium.

When a solution of chloride of palladium is partially precipitated by means of a solution of potash or of soda, care being taken that the metallic chloride shall still be present in considerable excess, a dark brown powder is obtained, which is a definite oxychloride of palladium.

When dried in a stove at a temperature of 150°, its properties are as follows:—if it be heated, it gives off water, and at a full red heat chlorine and oxygen, leaving behind a mixture of subchloride, suboxide, and metal. It dissolves in dilute acids, giving a mixture of protochloride and an ordinary palladium salt of the acid used.

Its analysis was conducted as follows:—

A. 40·639 grains fused with carbonate of soda and the saline mass dissolved in water left 28·508 grains of palladium, purely metallic, being equal to 69·80 per cent.

The solution acidulated by nitric acid and precipitated by nitrate of silver, gave 18·103 grains of chloride of silver, or 44·55 per cent., containing 10·99 of chlorine.

B. 67·543 grains of another specimen were heated over a spirit-lamp as long as any watery vapour came off, but not so high as to expel any traces of chlorine or oxygen. The dry mass which remained weighed 59·977 grains, being 88·62 per cent. The loss of water had thus been 11·38 per cent.

This dry residue was then vividly ignited and a lump of carbonate of ammonia introduced to favour the separation of the chlorine. The metallic palladium which remained weighed 47·442 grains, or 70·25 per cent.

These results lead to the formula $Pd\,Cl + 3\,Pd\,O + 4\,H\,O$, which gives,—

	Theory.		Experiment A.	Experiment B.
$4\,Pd =$	213·2	69·10	69·80	70·25
$3\,O =$	24·0	7·77		
$Cl =$	35·4	11·47	10·99	
$4\,H\,O =$	36·0	11·66		11·38
	308·6	100·00		

It is therefore quite analogous to the ordinary oxychloride of copper.

Of the Ammonia-chlorides of Palladium.

It is well known that on adding water of ammonia to a solution of chloride of palladium, a pink-coloured precipitate is produced, which by boiling dissolves, giving a brownish yellow liquor, from which on cooling a crystalline yellow substance separates. These two bodies have the same per cent. composition, expressed by the formula $Pd\,Cl + N\,H_3$. Of this I need not detail any evidence, as it has been fully established by the labours of Berzelius, and quite recently by the experiments of Fehling.

By means of an excess of ammonia, the pink red precipitate which first forms may be totally redissolved, giving a colourless solution, from which by evaporation, a salt is deposited on cooling, in colourless rectangular prisms. The existence of this salt has been long known, and as its analysis has been recently published by Fehling, I need not detail any of my own experimental results, which fully coincide with his. The formula of this body is $Pd\,Cl + 2\,N\,H_3 + H\,O$, or rationally, according to the principles I have elsewhere laid down for the copper salts, $N\,H_4 . Cl + Pd\,O . N\,H_3$. When gently heated it evolves water and ammonia, and leaves the yellow substance $Pd\,Cl + N\,H_3$. The same decomposition may be effected by evaporating its solution to dryness, in which case the yellow salt generally crystallizes in cubes. Were it not hazardous to draw any inference with regard to the isomorphism of bodies belonging to the regular system, I should notice this fact as illustrative of the equivalency of $Pd\,Cl . N\,H_3$ with K. By a very cautious application of heat to the colourless crystallized salt, some water may be expelled before the ammonia begins to come off, but I have never succeeded in rendering it quite anhydrous. It however partially assumes the formula $N\,H_4 . Cl + Pd . N\,H_2$, to which we shall find the ammonia-sulphate of palladium to present an equivalent.

By the action of solutions of caustic potash on solutions of these ammonia-chlorides of palladium, a variety of products are formed, according to the proportions employed and the circumstances of temperature. For the complete investigation of these bodies I have not yet accumulated materials, but the results which have been already obtained are not without interest as indicative of the analogies of palladium to other metals whose laws of combination are better known. I shall consequently describe those substances I have as yet examined, although I intend to resume and extend their investigation before long.

A. When the pink-red precipitate is boiled with a large quantity of water it dissolves, and on cooling but little of the isomeric yellow salt crystallizes out. On adding to the brownish yellow liquor so obtained a solution of caustic potash not in excess, a yellowish precipitate falls, which by boiling becomes brown red, and distinctly crystalline. If the pink red substance ($Pd\,Cl + N\,H_3$) be dissolved in the hot water without much boiling, there is generally no precipitate on adding the caustic potash, and the solution is merely yellow, not brownish coloured. It appears necessary that, by the boiling, partial decomposition should occur, and some ammonia be ex-

pelled to bring the liquor to the state suitable for the action of the caustic potash. This may also be effected by adding to the solution of the ammonia-chloride some solution of protochloride of palladium, so as to have in solution apparently a substance containing $Pd\,Cl + Pd\,Cl\,.\,N\,H_3$, which is not known in the solid form.

The yellow precipitate which first falls is the ordinary crystalline body $Pd\,Cl + N\,H_3$, but by boiling in the liquor from which it has separated, its nature is completely changed. The properties of the crystalline brown red substance then produced are, that it dissolves readily in muriatic acid, and gives by heat, sal-ammoniac, nitrogen and water, and leaves metallic palladium. Its composition was determined by analysis to be as follows:—

I. 14·601 grains having been ignited to perfect fusion with carbonate of soda, gave, when the saline material was dissolved in water, 8·072 grains of palladium, or 55·28 per cent.

The solution acidulated with nitric acid and precipitated by nitrate of silver, gave 14·802 grains of chloride of silver, equivalent to 101·4 per cent., containing 25·03 of chlorine.

II. 7·964 grains of substance gave, by the method pursued in similar instances, 3·3907 cubic inches of nitrogen, at standard temperature and pressure. These weigh 1·080 grains, equal to 13·64 per cent.

III. 9·231 grains of substance having been mixed with dry carbonate of soda, were introduced into a tube of Bohemian glass, and some pieces of platina foil being interposed, about four inches of the tube in front of the mixture were filled with oxide of copper. To this apparatus was adapted a tube containing recently fused chloride of calcium, and the whole being disposed and heated exactly as for an organic analysis, it yielded 3·212 grains of water, being 34·78 per cent., containing 3·85 of hydrogen.

After this operation, the tube being cut by a file, that portion of it which contained the saline mass was digested with dilute nitric acid, and the metallic palladium collected on a filter. It weighed 5·170 grains, or 56·02 per cent.

The solution treated in the usual way gave 9·337 of chloride of silver, or 101·2 per cent., containing 24·92 of chlorine.

The summary of these results is

	I.	II.	III.
Palladium	55·28		56·02
Nitrogen		13·64	
Hydrogen			3·85
Chlorine	25·03		24·92

The deficiency in the sum of the preceding results being counted as oxygen, these numbers lead to the formula $Pd_3\,Cl_2\,O\,N_3\,H_9$, which gives

3 . Pd =	159·9	55·20
2 . Cl =	70·8	24·44
O =	8·0	2·76
9 . H =	9·0	3·10
3 . N =	42·0	14·50
	289·7	100·00

This body may be considered as a compound of ammonia-chloride with ammonia-oxide of palladium, thus 2 ($Pd\,Cl\,.\,N\,H_3$) + $Pd\,O\,.\,N\,H_3$, and its origin explained, by an atom of potash producing with three atoms of ammonia-chloride, it and chloride of potassium, for 3 ($Pd\,Cl\,.\,N\,H_3$) and $K\,O$ give $Pd_3\,Cl_2\,O\,N_3\,H_9$ and $K\,Cl$. I shall, however, return to the notice of its rational constitution when the next substance has been described.

B. When the same kind of palladium liquid from which the brown red substance last noticed is prepared, is heated with an excess of solution of caustic potash in the cold, a whitish powder falls, which on drying, even by a very gentle heat, becomes dark olive-coloured. If it be boiled its colour changes to yellow, and is then found to be identical with the yellow crystalline body ($Pd\,Cl\,.\,N\,H_3$) which makes its appearance under such various circumstances. This olive-coloured substance when heated evolves water and vapours of sal-ammoniac, leaving metallic palladium. Its analysis gave the following results:—

12·224 grains gave, by fusion with carbonate of soda and decomposition by nitrate of silver, in the usual manner, 8·242 grains of metallic palladium, equivalent to 67·43 per cent., and 5·939 grains of chloride of silver, being 48·48 per cent., containing 11·96 per cent. of chlorine.

12·113 grains, heated with oxide of copper as for an organic analysis, gave 2·423 of water, being 20·03 per cent., containing 2·22 per cent. of hydrogen.

Hence the formula expressing the composition of this body appears to be $Pd_4\,Cl\,N\,O_6\,H_6$, the numbers being

	Theory.		Experiment.
Pd_4	= 213·2	67·34	67.43
Cl	= 35·4	11·18	11·96
N	= 14·0	4·43	18·39
O_6	= 48·0	15·16	
H_6	= 6·0	1·89	2·22
	316·6	100·00	100·00

I regret very much that the quantity of this substance at my disposal did not allow me to make a distinct nitrogen determination at the time of the above analyses, and the difficulty of procuring either this or the preceding (A. red brown) body quite free from the crystalline yellow substance being very great, I have not had a subsequent opportunity. I shall however return to it, although I consider the arguments which might be brought forward in favour of the formula just now given to be very decisive for its reception: indeed no other formula that can reasonably explain the circumstances of the production of this body agrees with the numerical results of its analysis.

This empirical formula assumes more interest when rationally expressed: it becomes $Pd\,Cl + 3\,Pd\,O + N\,H_3 + 3\,H\,O$. It therefore consists of the ordinary oxychloride, with an atom of ammonia in place of one atom of its water of hydration, or it may be written $Pd\,Cl\,.\,N\,H_3 + 3\,(Pd\,O\,.\,H\,O)$, being a compound of ammonia-chloride and hydrated oxide. But it is more consonant to analogy to consider it as containing a metallic amidide, and its formula is then written $Pd\,Cl + 2\,.\,Pd\,O + Pd\,.\,N\,H_2 + 4\,H\,O$. It is thus the perfect analogue to the yellow powder produced by the action of water on the white precipitate of mercury, except that like all the copper and palladium bodies, it is hydrated, whilst the corresponding mercurial compounds are anhydrous. Such I consider to be the real constitution of this olive powder, and by our knowledge of its existence we are enabled to view the other ammonia-chlorides of palladium more intimately than previously had been possible. Thus the change of the pink ammonia-chloride to the yellow must, as I conceive, be attended with an alteration in the mode of combination of its elements. The pink body is formed only by the direct union of ammonia with chloride of palladium. It appears to be truly and simply $Pd\,Cl + N\,H_3$; but the yellow crystalline substance is produced only by processes in which the palladium has certainly passed, at least in a great degree, from union with chlorine, and has combined with oxygen or amidogene. It is hence most probable that the yellow substance cannot also be simply $Pd\,Cl + N\,H_3$. The arrangement of its elements may be expressed by the formula $H\,Cl + Pd\,.\,N\,H_2$, or else there may exist for palladium a compound analogous to the mercurial white precipitate, its formula being $Pd\,Cl + Pd\,N\,H_2$, and this combined with sal-ammoniac may form the yellow substance, precisely as the true white precipitate $(Hg\,Cl + Hg\,.\,Ad)$ by union with sal-ammoniac forms Wöhler's white precipitate, the composition of which, as I have elsewhere shown, is expressed by the simple formula $Hg\,Cl + N\,H_3$.

C. By boiling a solution of the colourless crystalline ammonia-chloride of palladium $(Pd\,Cl + 2\,N\,H_3 + H\,O)$ with caustic potash in excess, for a long time, an olive-green powder falls, which when heated deflagrates like loose gunpowder. A quantity of it which I had prepared for analysis and incautiously heated, was thus lost, and I can therefore merely indicate the existence of this body, and defer the exact account of it to a future time.

In the memoir already often alluded to, Fehling has noticed that, on dissolving the pink ammonia-chloride in boiling water, a small quantity of a brown powder is sometimes left undissolved, and on analysing it (determining only the content of metal and chlorine), he deduced that it had the formula $Pd_3\,Cl + 3\,N\,H_3$. He remarks, however, that the origin of a body having that formula, is under the circumstances incomprehensible; it indeed assumes the existence of a peculiar chloride of palladium for which there is no other evidence whatsoever. I have on two occasions

examined this trace of brown matter, and found its composition variable, and that it contains oxygen, as it evolves water when heated. It is most probable that the ammonia-chloride is partially decomposed by water into the olive body (B.) and sal-ammoniac, thus 4 $(Pd . Cl . N H_3)$ and $2 . H O$ give $Pd_4 Cl O_2 N H_2$ and $3 . N H_4 Cl$, and that this olive substance (hydrated) combines with a certain quantity of ammonia-chloride, undecomposed, or is more probably but mixed with it. The formula $Pd_9 Cl_3 N_3 H_{15} O_{12} = Pd . Cl . N H_3 + 2 (Pd_4 Cl N H_6 O_6)$ gives very accurately the result obtained by FEHLING.

It may be remarked, however, that another and very interesting formula expresses the composition of FEHLING's substance. It is this: $Pd_3 Cl N_2 H_6 O_2$, or rationally, $Pd Cl + 2 . Pd N H_2 + 2 Aq.$ This gives

	Theory.		FEHLING.
Pd_3 . . .	159·9	65·18	64·18
Cl . . .	35·4	14·43	14·85
$2 N H_3$ . .	34·0	20·39	20·97
O_2 . . .	16·0		
	245·3	100·00	100·00

It should then be an oxychloride of palladium united to ammonia, or a hydrated chloramidide of palladium, analogous in constitution to the very peculiar oxychloride of copper, $Cu Cl + 2 Cu O$, which I have elsewhere described.

The observations I have had occasion to make respecting the iodides and cyanide of palladium, and the bodies derivable from them, agree perfectly with those obtained by FEHLING, and published in the memoir to which I have so often had occasion to refer, on the relation of the haloid compounds of palladium to ammonia, inserted in LIEBIG's 'Annalen der Chemie und Pharmacie.' I deem it hence unnecessary to notice any of those results in detail, as they already have been placed before the public.

Of the Sulphates of Palladium.

The sulphate of palladium is best prepared by dissolving the metal in a mixture of sulphuric acid and nitric acid, the former being in excess, and evaporating the deep brown red liquor so obtained to the consistence of a syrup. On cooling, it crystallizes, though very confusedly, and only when so concentrated as to become almost completely solid.

In this state it tastes sour and metallic. It is reddish brown coloured, very soluble in water, and in damp air deliquescent. It contains water of crystallization. Its composition was determined as follows:—

45·286 grains of the crystalline mass, dried between folds of bibulous paper, were heated cautiously as long as any traces of moisture were given off. The residual mass weighed 38·124 grains, or 84·19 per cent., having lost 15·81 per cent. of water.

Of the material so dried, 32·043 grains were fused with carbonate of soda, and the mass having been boiled with water, the palladium was collected on a filter and ignited. It was purely metallic, and weighed 16·653 grains, being 51·97 per cent. of the dry, or 43·75 per cent. of the hydrated salt.

The liquor filtered from the metallic palladium was acidulated by muriatic acid, and precipitated by nitrate of barytes. It gave 37·492 grains of sulphate of barytes, containing 12·997 grains of sulphuric acid, equivalent to 40·17 per cent. of the dry, and to 33·82 per cent. of the hydrated salt.

These results give therefore for the

	Dry Salt.	Hydrated Salt.
Water		15·81
Sulphuric acid .	40·17	33·82
Palladium . . .	51·97	43·75
Oxygen and loss .	7·86	6·62
	100·00	100·00

The formula $Pd\,O\,.\,S\,O_3 + 2\,.\,H\,O$ gives

	Dry Salt.	Hydrated Salt.
Water		15·08
Sulphuric acid .	39·54	33·58
Palladium . . .	52·56	44·64
Oxygen	7·90	6·70
	100·00	100·00

When the dried sulphate of palladium is exposed to the air it rapidly re-acquires water to the extent of one equivalent, without becoming sensibly damp. This quantity was determined several times; the proportion being that 100 parts of the dry salt regained nine to ten parts of water, forming therewith a greenish olive powder. If the air be very damp, it subsequently deliquesces completely. By this property the sulphate of palladium appears to ally itself with the sulphates of copper, magnesia, &c., but it differs widely from them in others. Thus it is decomposed by water, and I could not succeed in forming any double salts by bringing it into contact with the alkaline sulphates. Its analogue here would appear to be the sulphate of mercury.

Basic Sulphate of Palladium.

When a strong solution of sulphate of palladium is mixed with much water it is decomposed; a deep brown powder is separated, and the liquid becomes very acid. By the addition of free sulphuric acid this action of water may be prevented; but on neutralizing this excess of acid by an alkali, even ammonia, a brown powder separates, which is found on analysis to be identical with the former.

The following analyses were made of specimens of this salt, prepared under various circumstances.

A. Prepared by dilution with water.

39·467 grains were heated over a spirit lamp cautiously until all water had been given off. The dry mass, which had become much darker in colour, weighed 35·994 grains, or 91·2 per cent., having lost 8·80 of water.

The dry powder was fused with carbonate of soda, and the metallic palladium collected precisely as described in the preceding article. It weighed 29·215 grains, or 73·68 per cent.

By the addition of nitrate of barytes the sulphuric acid was determined; it amounted to 2·408 grains, or 6·11 per cent.

B. Prepared by the addition of potash.

The method of analysis was precisely as in the foregoing instance.

23·645 grains of material gave when dried 21·670 grains, or 91·64 per cent., having lost 8·36 of water.

This residue gave 17·379 grains of palladium, being 73·49 per cent.; and then 4·569 grains of sulphate of barytes, being 19·36 per cent., containing 6·65 of sulphuric acid.

C. A portion of the same specimen having been exposed to the air for some time was analysed.

27·443 grains gave when dried 23·722 grains, or 86·45 per cent., having lost 13·55 of water.

This residue was ignited with carbonate of ammonia. It left 19·215 grains of metallic palladium, equivalent to 70·02 per cent.

This basic salt had, therefore, by exposure to the air, regained a quantity of water of which it had been deprived by the high temperature of the stove in which the drying of the precipitates had been effected.

D. Prepared by ammonia, not added in excess, and dried at about 150° Fahr.

I. 47·072 grains of material gave, by a temperature near, but still below, redness in the dark, 40·361 grains of dry substance, being 85·74 per cent. It had thus lost 14·26 of water.

By fusion with carbonate of soda, and treatment in the usual manner, were obtained 32·444 grains of metallic palladium, and 9·800 grains of sulphate of barytes. These weights indicate 68·91 per cent. of metal, and 7·15 of sulphuric acid.

II. 24·780 grains of this specimen were heated until all water was given off; it then weighed 21·159 grains, having lost 14·58 per cent. The dry salt was then exposed to a damp atmosphere for twenty-four hours; it did not increase very sensibly in weight. This basic sulphate has, therefore, no power to reassume the hydrated condition, having once been fully dried.

This dry material was fused with carbonate of soda, and the metal and sulphuric acid determined by the usual methods. It gave 16·977 grains of palladium, or 69·47 per cent., and 4·275 grains of sulphate of barytes, indicating 6·94 of sulphuric acid per cent.

The analyses A. B. and C. would tend to show that this salt may exist in two degrees of hydration, but I rather think that the difference is not important, for in heating the other specimens I could not trace any distinct term at which an interruption to the evolution of the water occurred. In the first examples, the specimens had been dried in the stove at a temperature which would have probably rendered them quite anhydrous, had they been exposed to its influence for a much longer time.

I shall exhibit the results of all the analyses as follows :—

	A. by Water.	B. by Potash.
Water	8·80	8·36
Sulphuric acid .	6·11	6·65
Palladium . . .	73·68	73·49
Oxygen and loss .	11·41	11·50
	100·00	100·00

	C. by Potash.	D. I.	D. II. by Ammonia.
Water	13·55	14·26	14·58
Palladium . . .	70·02	68·91	68·53
Sulphuric acid . .	16·43	7·15	6·94
Oxygen and loss . .		9·68	9·95
	100·00	100·00	100·00

It is thus abundantly evident that there exists but the one basic sulphate of palladium which may be prepared by the action of water or of any alkali upon the sulphate, and the analyses given indicate that the dry salt has the formula $SO_3 + 8\,PdO$, from the per cent. composition of which none of the results found vary much, whilst the mean of all coincides completely with it. Thus,

		Theory.	Mean of analyses abstracting water.
8 Pd . =	426·4	80·38	80·72
8 O =	64·0	12·06	11·42
SO_3 =	40·1	7·56	7·86
	530·5	100·00	100·00

The two hydrated states of this salt are accurately expressed by the formulæ

$$SO_3 + 8\,.\,PdO + 6\,HO, \text{ and } SO_3 + 8\,.\,PdO + 10\,HO,$$

which give in numbers,

8 Pd =	426·4	72·96	8 Pd =	426·4	68·72
8 O =	64·0	10·95	8 O =	64·0	10·32
SO_3 =	40·1	6·85	SO_3 =	40·1	6·47
6 . HO =	54·0	9·24	10 . HO =	90·0	14·49
	584·5	100·00		620·5	100·00

Of the Ammonia-sulphates of Palladium.

On adding water of ammonia to a solution of sulphate of palladium, no ammoniacal compound is at first obtained, but merely the basic compound already described. When, however, the ammonia is added in excess, the basic salt redissolves, and a colourless liquor is produced, from which the ammonia-sulphate may be obtained crystallized, by cautious evaporation and cooling.

This salt is best obtained by taking a strong solution of the neutral sulphate, and passing into it a stream of ammoniacal gas until the brown precipitate which first appears is totally redissolved; then filtering, if necessary, and setting aside to cool slowly. It then forms rectangular prisms, often of considerable size and of a beautiful pearly lustre.

When this salt is very gently heated, it gives off water, and the crystals become opake, but without losing their form or whiteness. Ammonia is next evolved, and the salt changes into a yellow powder, which, when more strongly heated, fuses, evolves sulphite of ammonia, ammonia, nitrogen, and water, and leaves metallic palladium.

A very finely crystallized specimen was analysed as follows:—

A. 25·987 grains decomposed by very full ignition gave 9·414 grains of palladium, or 36·24 per cent.

B. 48·677 grains dried at a very moderate heat as long as any water was evolved, but without any loss of ammonia, and remaining quite white, then weighed 45·672 grains, having lost 6·19 per cent. of water.

17·039 grains of this dry material gave by bright ignition 6·591 grains of palladium, which is 38·68 per cent. for the dry, and 36·28 for the hydrated salt.

C. 28·462 grains of the crystals were fused with carbonate of soda and the mass treated with boiling water. The metallic palladium which remained weighed 10·340 grains, or 36·50 per cent.

The alkaline liquor acidulated by nitric acid and treated with nitrate of barytes, gave 22·827 grains of sulphate of barytes, indicating 27·67 per cent. of sulphuric acid.

These results may be thus exhibited.

	Hydrated Salt. A.	B.	C.	Dry Salt.
Water		6·19		
Sulphuric acid . .			27·67	29·49
Palladium . . .	36·24	36·28	36·50	38·68

These results abundantly show that the formula of this salt is, when crystallized, $SO_3 + PdO + 2NH_3 + HO$, which gives

SO_3 =	40·1	27·75
Pd =	53·3	36·95
O =	8·0	5·54
$2.NH_3$ =	34·0	23·53
HO =	9·0	6·23
	144·4	100·00

I have shown elsewhere* that the sulphates of this class must be considered as consisting of an ordinary ammoniacal salt united to a metallic oxide combined with ammonia, or to a true metallic amidide. Of these two states, the ammoniacal sulphates of copper and of silver afford examples, the former having the formula $S\,O_3 . N\,H_4\,O + Cu\,O . N\,H_3$, whilst that of the latter is $S\,O_3 . N\,H_4\,O + Ag . N\,H_2$. The salt of palladium, at present in question, affords an excellent instance of the passage from the one to the other state, for as the crystals lose their water by a gentle heat, and the quantity of it amounts to exactly an equivalent, the formula of the dried salt becomes $S\,O_3 . N\,H_4\,O + Pd . N\,H_2$, and there is hence good ground for the opinion that the atom of water is really present as such in the hydrated salt, and that in this, and also in the corresponding salts of nickel, cobalt, copper, and zinc, the metal is truly combined with amidogene. The formula is then to be written for this, as for all such salts, $S\,O_3 . N\,H_4\,O + Pd . Ad + Aq$.

There exists another ammonia-sulphate of palladium, which may be formed by the action of a moderate heat upon that already described, until it is totally converted into a yellow powder, or it may be produced by adding sulphuric acid to a strong solution of the preceding salt, or by boiling such solution for a long time. It then precipitates as a yellow crystalline powder, which dissolves easily in boiling, but very sparingly in cold water. By a strong heat it is decomposed into water, and gaseous products, sulphite of ammonia, and metallic palladium.

It was analysed by fusion with carbonate of soda, treatment of the residue with water and determination of the sulphuric acid, as sulphate of barytes. From 27·103 grains there were thus obtained 12·128 grains of metal, or 44·70 per cent., and 26·886 grains of sulphate of barytes, or 99·8 per cent., containing 34·40 of acid.

The formula deducible from these numbers is $S\,O_3 . Pd\,O + N\,H_3$. Thus there is

	Theory.		Experiment.
Sulphuric acid .	40·1	33·87	34·30
Palladium . . .	53·3	45·02	44·70
Oxygen	8·0	6·75	21·00
Ammonia . . .	17·0	14·36	
	118·4	100·00	100·00

On adding muriatic acid to a solution of the white ammonia-sulphate, it is not this salt which separates, but the yellow ammonia-chloride already noticed.

Of the Nitrates of Palladium.

It has been long known that palladium dissolves in nitric acid without any evolution of nitric oxide gas unless heat be applied. On evaporating the olive-brown

* Transactions of the Royal Irish Academy, vol. xix. p. 77.

solution so obtained, it becomes more reddish, and if set aside when of a sirupy consistence, and allowed to cool slowly, the nitrate of palladium crystallizes in long rhombic needles, which are, however, so deliquescent that I found it impossible to determine with accuracy the quantity of water of crystallization which they contain. In general, the solution of this salt dries down to a mass with scarcely any trace of crystalline structure.

If a solution of nitrate of palladium be diluted with much water, a dark brown powder falls, which is a basic nitrate. It may be generated also by adding solution of potash, or water of ammonia in small quantity, to a solution of the metallic salt. This basic nitrate, when heated, evolves water, and then red fumes of nitrous acid; leaving oxide or suboxide of palladium, according to the temperature to which the material may have been finally exposed.

The following analyses will show that the basic nitrate, as prepared by different methods, is really of uniform constitution.

A. Basic nitrate prepared by water of ammonia.

60·808 grains of this specimen were placed in a tube of Bohemian glass, about twelve inches long, and in front of this, but completely separated by some rolled pieces of platinum foil, the tube was filled for a space of about four inches, with clean finely-divided metallic copper, as reduced from the oxide by hydrogen gas. To each end of the tube was attached a bulb-tube, containing recently fused chloride of calcium, and that next the metallic copper was placed, by a caoutchouc connecter, in communication with a vessel of water, by the flowing out of which a current of air might be established through the apparatus, precisely as is effected in the process proposed by Liebig for drying organic substances previous to analysis. The long tube containing the palladium salt and the metallic copper being placed in a charcoal furnace, that portion containing the copper was heated to redness, and then, whilst by the flowing out of the water a stream of air was brought through the tube, a gentle heat was applied to the basic nitrate of palladium. Water and red fumes were given off, which latter were reduced to the state of nitrogen or nitrous oxide by contact with the ignited metallic copper. The current of air, which had been accurately dried by passing through the first chloride of calcium tube, carried these products forwards. The water was collected by the chloride of calcium tube into which it passed, whilst the gases mixing with the general current of the air passed into the vessel from which the water flowed.

As soon as the palladium salt had been feebly ignited, the process was interrupted, and the tube allowed to cool. It was then so cut by a file, as that the residual oxide of palladium could be removed without any sensible loss. It weighed 44·620 grains, or 73·15 per cent. The chloride of calcium tube in which the water had been collected, was weighed before and after the operation. The increase of weight was 7·208 grains, indicating 11·85 per cent. of water.

In order to verify the degree of oxidation and determine the quantity of metal in

the residual oxide, the 44·620 grains were ignited in a current of hydrogen gas, and the water so formed was collected in a chloride of calcium tube. It weighed 6·251 grains, or 10·28 per cent., containing 9·14 of oxygen, and the remaining metallic palladium weighed 38·927 grains, corresponding to 64·01 per cent.

B. Basic nitrate produced by water.

I. 29·665 grains of the brown precipitate, formed by diluting a strong solution of nitrate of palladium with a large quantity of water, gave, by very gentle ignition, a black residue of oxide weighing 21·747, or 73·31 per cent., and by vivid ignition 18·939, or 64·36 per cent. of pure metallic palladium.

II. 12·858 grains were mixed with copper filings, and more clean metallic copper being placed in front, the tube was heated in the same manner and with the same arrangement of apparatus as already described in A. The water collected in the chloride of calcium tube weighed 1·420, corresponding to 11·20 per cent.

III. 17·239 grains were mixed with copper turnings, and placed at the bottom of a tube of Bohemian glass, which was then filled with clean freshly-reduced metallic copper. The tube was about nine inches long. From it passed to the pneumatic trough a bent tube, of which the extremity opened, above the level of the water, under a narrow graduated jar, so adjusted as that it should rise as gas passed into it. The pure metallic copper having been first fully ignited, heat was applied to the extremity of the tube, and the nitric acid of the salt was so completely deoxidized by the red-hot copper, that the gas which passed over contained no sensible trace of nitric oxide. When the operation was concluded the apparatus was allowed to cool, and the proper correction being made for the change of temperature which had taken place in the air of the room during the experiment, the volume of the gas collected in the graduated jar was considered to represent the quantity of nitrogen which the substance contained. After the proper corrections for temperature, pressure, and moisture, it measured 2·319 cubic inches, weighing 0·7452 grains, or 4·31 per cent.

By this method the composition of the basic nitrate of palladium is found to be

	A. By Ammonia.	B. By Water. I.	II.	III.
Palladium	64·01	64·36		
Oxygen combined with metal	9·14	8·95		
Water	11·85		11·20	
Nitrogen				4·31

These results lead to the simple formula $N\,O_5 + 4\ Pd\,O + 4\ H\,O$, which gives

$4\ Pd =$	213·2	63·61
$4\ O =$	32·0	9·54
$N =$	14·0	4·17
$O_5 =$	40·0	11·94
$4\ H\,O =$	36·0	10·74
	335·2	100·00

$4\ .\ Pd\,O =$	245·2	73·15
$N\,O_5 =$	54·0	14·91
$4\ H\,O =$	36·0	11·94
	335·2	100·00

Ammonia-nitrates of Palladium.

A. When a solution of nitrate of palladium is heated with a considerable excess of water of ammonia, or when ammoniacal gas is passed into the solution, a colourless liquor is ultimately obtained, the precipitate which first forms being perfectly redissolved. By careful evaporation, this solution deposits a pure white salt in rhombic crystals (prisms or plates), of a brilliant pearly lustre. When heated, this salt fuses, and deflagrates violently with a brilliant white flame, depositing metallic palladium, and evolving water and nitrogen gas. The existence of this salt and its property of so exploding has been long known, and its composition only remained to be determined by me.

I. 20·696 grains of this salt in good crystals were mixed with powdered glass, and placed in a tube: in front of the mixture was put oxide of copper, and in front of that again clean metallic copper, in thin turnings. The latter part of the tube having been heated to redness, heat was applied to the part of the tube containing the mixture, and the gas and watery vapour brought into contact with the oxide and metallic copper. The water was collected in a chloride of calcium tube, the last portions being obtained by breaking open the far extremity of the analysis tube which had been formed to a point for the purpose, and drawing by the mouth a current of air through the apparatus: the quantity of water was 8·180, or 39·53 per cent., containing 4·39 of hydrogen.

II. 16·036 grains were mixed with powdered glass, and heated in a platinum crucible, at first gently, until all volatile products had been expelled, but then to dull redness. The weight of the glass used being known, it was found that there remained of metallic palladium 5·725, or 35·71 per cent.

III. 16·237 grains being mixed with powdered glass and placed in a tube with oxide of copper and metallic copper as in the last experiment, but from which a narrow tube passed to a graduated jar in the water-pneumatic trough, the decomposition was effected, and the volume of the nitrogen gas evolved determined as already noticed in the analysis of the basic nitrate. It measured 14·7075 cubic inches, weighing 4·7149 grains, equivalent to 29·04 per cent.

The composition of this salt is, therefore,

Palladium	35·71	100·00
Nitrogen	29·04	
Hydrogen	4·39	
Oxygen (by loss) . . .	30·86	

The formula $NO_5 + PdO + 2 . NH_3$, exactly agrees with these results, giving

$Pd = 53·3$	35·70	$PdO = 61·3$	41·09
$N_3 = 42·0$	28·13	$NO_5 = 54·0$	36·12
$O_6 = 48·0$	32·15	$2 . NH_3 = 34·0$	22·79
$H_6 = 6·0$	4·02	149·3	100·00
149·3	100·00		

The rational formula of this salt is, therefore, $N O_5 . N H_4 O + Pd . N H_2$, and it is completely analogous in constitution to the corresponding ammoniacal nitrate of copper.

B. If the quantity of ammonia added to the solution of nitrate of palladium be not sufficient to redissolve all of the brown basic nitrate which is first formed, a deep yellow liquor is produced, which deposits on standing, or by moderate concentration, small yellow crystals, whose form appears to be rhombic-octohedral. When heated, these crystals deflagrate, producing water and nitrogen gas with copious fumes of nitrous acid, and some clouds of nitrate of ammonia. The residue after ignition is metallic palladium.

The analysis of this body was conducted as follows:—

I. 6·065 grains were ignited in a tube of Bohemian glass, and the volatile products having been conducted over red-hot metallic copper to decompose any red fumes, were passed through a tube containing chloride of calcium, which collected water amounting to 1·219 grains, or 20·10 per cent., corresponding to 2·23 of hydrogen in 100·00.

The tube being cut the residual palladium was found to weigh 2·623 grains, or 43·6 per cent.

II. 5·016 grains ignited in a platinum crucible gave 2·285, or 45·54 per cent. of metal.

III. 5·571 grains gave when treated exactly in the manner described in the preceding salt, nitrogen gas, which after correction measured 4·211 cubic inches, weighing 1·355 grain, or 24·10 per cent. The decomposition did not appear to proceed so regularly, nor to give so pure gas as in other cases.

From these experiments this compound appears to contain in 100 parts,

Palladium	43·60	45·54
Nitrogen	24·10	
Hydrogen	2·23	
Oxygen (by loss) . . .	30·07	
	100·00	

The formula to which these numbers lead is very anomalous. It is $N O_5 + Pd . N H_2$, which gives

One atom palladium . .	53·3	43·23
Two atoms nitrogen . .	28·0	22·71
Two atoms hydrogen . .	2·0	1·62
Five atoms oxygen . . .	40·0	32·44
	123·3	100·00

If this formula were perfectly established it would constitute the first example of a direct combination of a metallic amidide with an acid. The only other supposition at all possible is, that it may contain the elements of an atom of water; the formula

should then become $N\,O_5 + Pd\,O\,.\,N\,H_3$, and correspond to the yellow crystalline form of the ammonia-chloride $Pd\,.\,Cl + N\,H_3$, or the yellow ammonia-sulphate, $S\,O_3\,.\,Pd\,O + N\,H_3$. Adopting this formula, the composition of the salt should have been

One atom palladium . .	53·3	40·29
Two atoms nitrogen . .	28·0	21·16
Three atoms hydrogen .	3·0	2·27
Six atoms oxygen . . .	48·0	36·28
	132·3	100·00

And with this the hydrogen and nitrogen determinations might be considered as perfectly agreeing. However, from the irregular way in which this salt is decomposed I attach little value to the nitrogen result, and, on the other hand, the quantity of palladium found exceeds that given by the formula as last written, too much to be accounted for by any error of experiment, as the crystals analysed were very pure. I hence consider that although the formula $N\,O_5 + Pd\,O\,.\,N\,H_3$ agrees best with our received ideas, and with the analogies of other compounds, yet the former, $N\,O_5 + Pd\,.\,N\,H_2$, is more strictly deducible from the analytical results, and deserves at least provisional adoption until an opportunity presents itself of obtaining more decisive results, for I have found that this substance is not formed in all cases when its elements are brought together. I have procured it crystallized and sufficiently pure for analysis but twice, and then only in such small quantity as limited my power of experiment, as has been already seen.

Double Oxalate of Palladium and Ammonia.

This salt, which may be formed by adding oxalic acid to a solution of any colourless ammonia-salt of palladium, or by dissolving the freshly-precipitated hydrated oxide, or basic carbonate in a solution of binoxalate of ammonium, crystallizes in very beautiful bronze-yellow rhombic prisms, which are of two kinds, differing in the quantity of water of crystallization which they contain. I shall describe them as being, the one form in short prisms, the other in needles.

The short prismatic salt gave on analysis the following results:—

31·225 grains gave, when very gently heated until the evolution of watery vapour ceased, 27·624 of dry salt, being 88·43 per cent.

This dry substance being then ignited there remained 9·429 grains of metallic palladium, or 30·20 per cent.

A quantity of the salt having been mixed with oxide of copper and introduced into a tube of German glass, with clean metallic copper in front, it was burned as for an organic analysis, and the relative volumes of nitrogen and carbonic acid in the gaseous mixture, which came over, were determined in the usual way. This relation varied very much in the different tubes full of gas, showing that the constituents of

the salt were not uniformly acted on by the heat, but the relation of the total volume of nitrogen to the total volume of carbonic acid was very exactly 1 : 4.

These results show that the formula of this salt is $Pd . O . C_2 O_3 + N H_4 O . C_2 O_3 + 2 Aq$, giving

		Theory.	Experiment.
Pd	= 53·3	30·06	30·20
$2 . C_2 O_4$	= 88·0	49·64	58·23
$N H_4$	= 18·0	10·15	
$2 . Aq$	= 18·0	10·15	11·57
	177·3	100·00	100·00

The salt crystallizing in long needles, gives, when dried, about 70 per cent. of dried salt, having lost 30 per cent. of water. By ignition it yields from 23 to 23·26 of metallic palladium. These numbers point out that it contains eight atoms of water of crystallization, from which the numbers should be 31·13 of water, and 23·04 of metal.

Section II.—Platinum Compounds.

Protoxychloride of Platinum.

During experiments conducted for the purpose of preparing sulphate of the deutoxide of platinum, and the results of which I shall on another occasion more specially describe, I had occasion to remark the formation of the substance now in question, and to determine its properties and composition. The bichloride of platinum being boiled with strong sulphuric acid in a retort, nearly to dryness, much muriatic acid gas is driven off, and on washing out the residue with water, a black powder remains undissolved, which may be collected on a filter. It is anhydrous. At a red heat it evolves oxygen and chlorine, leaving metallic platinum. In solution of potash it appears to dissolve. By ammonia it is converted into a fulminating substance, of which the analysis is not yet completed. By muriatic acid it is converted into the ordinary protochloride of platinum.

Its analysis was effected as follows :—

29·402 grains were perfectly fused with an excess of carbonate of soda. When the saline matter was dissolved out with water, metallic platinum remained which weighed 25·620 grains, or 87·14 per cent. The solution having been precipitated by nitrate of silver, after being acidulated by nitric acid, gave 8·995 of chloride of silver, or 30·55 per cent., containing 7·54 of chlorine.

These results lead to the formula $Pt Cl + 3 Pt O$, which gives

		Theory.	Experiment.
Pt_4	= 395·2	86·94	87·14
Cl	= 35·4	7·78	7·54
O_3	= 24·0	5·28	5·32
	454·6	100·00	100·00

The material which is dissolved off from this black powder is by no means a pure sulphate of platinum. It contains also bichloride, the decomposition of which appears to have a definite limit regarding sulphuric acid.

Action of Ammonia on Biniodide of Platinum.

When the biniodide of platinum is digested in water of ammonia, either cold or hot, it becomes gradually changed to a bright cinnabar red powder, which is insoluble in water. This powder may also be formed by adding water of ammonia to a solution of the double iodide of platinum and potassium. The liquor becomes nearly colourless, and the red substance precipitates.

On heating this body it gives off ammonia with fumes of iodine and of hydriodate of ammonia: water also separates. It may, however, be exposed to a temperature of 350° Fahr. without losing water, which does not escape until complete decomposition has commenced.

The analysis of this body was effected as follows:—

32·490 grains were fused with carbonate of soda, and the residual mass digested in water. The platinum which remained behind weighed 12·472, or 38·01 per cent.

The alkaline solution being rendered acid by acetic acid, was decomposed by nitrate of silver. The iodide of silver, being collected, dried and weighed, was 29·295 grains, or 89·8 per cent., containing 48·37 of iodine.

47·226 grains, ignited with oxide of copper in the manner already described, gave 9·215 cubic inches of dry nitrogen, equivalent to 6·26 per cent. in weight.

44·468 grains, ignited with oxide of copper, gave 4·584 of water, equivalent to 1·15 of hydrogen per cent.

These results lead directly to the formula $Pt\,I\,N\,H_4\,O_2$. or $Pt\,O_2 + N\,H_4\,.\,I$., for which the numbers are

	Theory.		Experiment.
Pt =	98·8	38·12	38·01
O_2 =	16·0	6·17	6·21
N =	14·0	5·44	6·26
H_4 =	4·0	1·54	1·15
I =	126·3	48·73	48·37
	259·1	100·00	100·00

The hydrogen being found below the quantity assigned by theory, I endeavoured to ascertain whether a portion of it could be eliminated as water, and I exposed a quantity of the substance to a current of dry air at 300° Fahr. until all traces of water ceased to pass. The quantity of water which escaped was 1·95 per cent. If this were not hygrometric, the formula of the dry substance should be $Pt\,I_2 + Pt\,O_2 + 2\,.\,N\,H_3$. and the hydrogen should be 1·20 per cent., nearly what was furnished by analysis. The specimen analysed for hydrogen was probably so dried.

It is interesting to find here the form assumed by the ammoniacal compounds of quicksilver, but still hydrated, and so rendered much more complex. It is curious also to recognise in the two hydrated states of this red platinum body, the analogues to the two formulæ assigned to the mercurial white precipitate before its true constitution was known. Thus $Pt\,O_2 + N\,H_4\,.\,I$. corresponds to the formula $Hg\,O_2 + N\,H_4\,.\,Cl$ given by MITSCHERLICH, and $Pt\,I_2 + Pt\,O_2 + 2\,.\,N\,H_3$ is equivalent to that suggested by Mr. RICHARD PHILLIPS, $Hg\,Cl_2 + Hg\,O_2 + 2\,.\,N\,H_3$. I do not believe, however, that the perfectly anhydrous condition of white precipitate can be given to this platinum body.

On the Action of Ammonia on the Perchloride of Platinum.

A. When a dilute solution of perchloride of platinum is added to water of ammonia, also dilute, a pale yellowish precipitate is produced, insoluble in cold water, but decomposed by boiling water, or even by much washing; the double chloride of platinum and ammonia being dissolved out, and the colour of the residue becoming much less yellow.

When this powder is heated it gives out sal-ammoniac, chlorine, nitrogen, and leaves metallic platinum. No trace of water appears: it hence does not contain oxygen as a constituent. With muriatic acid it is changed into the common double chloride of platinum and ammonium.

This substance was analysed as follows :—

21·098 grains were carefully mixed with an excess of carbonate of soda, and ignited until the mixture was completely fused. The saline matter was then dissolved out with distilled water, and the metallic platinum remaining being collected and ignited, weighed 10·881 grains, = 51·6 per cent.

The solution having been acidulated by nitric acid was precipitated by nitrate of silver, the chloride of silver produced was collected and fused, it then weighed 18·521, equivalent to 38·8 of chlorine per cent.

45·332 grains of another quantity, treated in a precisely similar way, gave 23·614 of platinum, = 52·1 per cent., and 70·151 of chloride of silver, equivalent to 38·20 of chlorine per cent.

These results indicate for the composition of this substance the very simple formula $Pt\,Cl_2 + N\,H_3$, which gives the numbers

	Theory.		Experiment.	
One atom of platinum	= 98·8	52·38	51·6	52·10
Two atoms of chlorine	= 70·8	37·94	38·8	38·20
One atom of ammonia	= 17·1	9·68	9.6	9·70
	186·7	100·00	100·0	100·00

From the circumstance of no water being produced when this body is decomposed by heat, and the relation between the chlorine and platinum showing that these con-

stituents are directly combined, the loss must necessarily be nitrogen and hydrogen in the proportions to form ammonia. This constituent, therefore, was not directly estimated; the analyses showing that the brownish yellow powder consists of an equivalent of perchloride of platinum united to an equivalent of ammonia.

This substance is not by any means always formed by the action of water of ammonia upon a solution of chloride of platinum; on the contrary, it is difficult to obtain it unless by using both solutions very weak, and by having the platinum quite free from muriatic acid in excess. In the great majority of cases, this first product is either rendered impure by the passage of a portion into the second stage of the reaction, or else by the precipitation of the double chloride of platinum and ammonium which is generated at the same time. With moderately weak solutions, the platinum being in excess, and avoiding too much washing of the precipitate, the substance may generally be obtained pure.

B. When the solutions of chloride of platinum and ammonia are boiled together, the precipitate rapidly assumes a remarkable fawn colour. In this state it is insoluble in water. It dissolves in muriatic acid, producing a yellow liquor. When heated, it gives off chlorine and muriatic acid gases, water, a trace of sal-ammoniac, and leaves metallic platinum.

The analysis of this body was effected as follows:—

I. 27·999 grains ignited with an excess of carbonate of soda, gave by the same mode of treatment as that described in paragraph A, 12·332 of platinum, being 44·24 per cent., and 47·365 of chloride of silver, equivalent to 41·94 in 100.

For the determination of the hydrogen and nitrogen, the same methods were employed as in the analyses of organic bodies, and the details of which need not be inserted.

20·064 grains burned with oxide of copper, gave 19·386 of water, or 2·17 per cent. of hydrogen.

20·049 grains of substance produced 4·29 cubic inches of dry pure nitrogen, equivalent at standard temperature and pressure to 1·420 grain, or 7·09 per cent.

II. Another quantity of substance prepared at a different time and at a much lower temperature, gave the following result:—

23·599 grains ignited with carbonate of soda, gave by treatment with nitric acid and nitrate of silver 40·223 chloride of silver, equivalent to 41·20 of chlorine per cent., and left 10·507 of platinum, equal to 44·47 in 100.

The hydrogen being determined, as in the former case, there was obtained from 24·925 grains of substance 5·170 of water, equivalent to 2·30 of hydrogen per cent.

In this instance the nitrogen was not determined. The formula to which these results lead is very remarkable, and will hereafter give origin to some observations; for

the present I shall only put it forward in a purely empirical form, as follows: $Pt_2 Cl_5 H_{11} N_2 O_4$, which gives the following numbers:—

Two atoms of platinum	= 197·6	44·35
Five atoms of chlorine	= 177·0	39·72
Two atoms of nitrogen	= 28·2	6·28
Eleven atoms of hydrogen	= 11·0	2·47
Four atoms of oxygen	= 32·0	7·18
	445·8	100·00

III. The substance used in analysis No. 1. was again boiled for a short time in water of ammonia, but without allowing the colour to become perceptibly altered, it was then dried at a temperature of 120°, and analysed.

14·462 grains of substance gave, by the usual treatment, 6·467 of metallic platinum, equivalent to 44·72 per cent., and 23·799 of chloride of silver, equivalent to 40·61 of chlorine.

24·139 grains of substance burned with oxide of copper gave 4·799 of water, or 2·21 of hydrogen per cent. 27·968 gave, by the usual method, 5·602 cubic inches of pure dry nitrogen, weighing at standard temperature and pressures 1·7961 grain, and hence equivalent to 6·44 per cent.

The experimental results are hence as follows:—

	I.	II.	III.
Platinum .	44·24	44·47	44·72
Chlorine .	41.94	41·20	40·61
Nitrogen .	7·09		6·44
Hydrogen .	2·17	2·30	2·21
Oxygen . .	4·56		6·92
	100·00		100·00

It is very remarkable that in all these results the chlorine appears to be a little (about 1 per cent.) above the theoretical number; this is perhaps due to the presence of traces of the double chloride of platinum and ammonium, which, from its sparing solubility, if once formed is very difficult to be removed, and is not changed, except when the accompanying bodies are also decomposed. The composition of this substance is, however, evidently the same, although prepared under varied circumstances; and it may also be produced, even in the cold, by allowing chloride of platinum to remain in contact with an excess of water of ammonia for a considerable time.

When this substance is heated to about 250° or 300° it abandons some water, but no ammonia. The quantity of water thus given off, was found to be 2·57 per cent. By the loss of one equivalent it should be 2 per cent., and hence probably the perfectly dried substance has the composition of $Pt_2\ Cl_5\ N_2\ H_{10}\ O_3$.

The formula of this body presents a remarkable relation, which may be at the pre-

sent moment noticed. It may be considered as the ordinary double chloride of ammonium and platinum, Pt Cl + N H Cl, united to a compound of chloride of platinum and oxide of ammonium, and then two atoms of water added. Thus

$$\left.\begin{array}{l} Pt\,.\,Cl_2 + N\,H_4\,Cl \\ Pt\,.\,Cl_2 + N\,H_4\,O \end{array}\right\} + 2\,Aq = Pt_2\,Cl_5\,N_2\,H_{10}\,O_3.$$

Whether this be its true constitution will be discussed in the sequel.

It may be also composed of the chloride of platinum and ammonium united to the body described in paragraph A. and to water. Thus

$$\left.\begin{array}{r} Pt\,Cl_2 + N\,H_4\,Cl\,. \\ Pt\,Cl_2 + N\,H_3 \quad\;\; \\ H_4\,O_4 \end{array}\right\} = Pt_2\,Cl_5\,N_2\,H_{11}\,O_4.$$

This is a more likely supposition than the former.

C. When the fawn-coloured substance last described is continually boiled in water of ammonia, it ultimately dissolves, but it may be observed to become dark brown before it disappears. This brown substance dissolves almost as soon as formed, and hence it is difficult to obtain a quantity of it for analysis; even a large quantity of chloride of platinum yielding by the action of ammonia only traces of it. This brown powder is not acted on by boiling water. With muriatic acid, it partly dissolves, giving a yellow liquor, and is partly converted into a white powder, sparingly soluble in water.

When heated it gives off sal-ammoniac, water and nitrogen, and metallic platinum remains. To determine the composition of this substance the same methods of analysis were used as in the former cases.

21·608 grains ignited with carbonate of soda, gave 13·455 of platinum, or 61·80 per cent., and then 9·939 of chloride of silver, corresponding to 11·35 of chlorine in 100.

23·799 grains gave, by ignition with oxide of copper, 7·085 of water, indicating 3·31 per cent. of hydrogen.

14·663 grains gave 6·2247 cubic inches of pure nitrogen reduced to 30 inches barometer and 32° Fahr., indicating 13·50 per cent. in weight.

The formula to which this analysis leads is remarkable; it is $Pt_2\,Cl\,N_3\,H_{10}\,O_4$, which gives the following numerical results:—

Two equivalents of platinum .	197·6	62·28	61·80
One equivalent of chlorine . .	35·4	11·16	11·35
Three equivalents of nitrogen .	42·3	13·33	13·50
Ten equivalents of hydrogen .	10·0	3·15	3·31
Four equivalents of oxygen . .	32·0	10·08	10·04
	317·3	100·00	100·00

The specimen employed in the above analysis had been dried at a temperature of 310°, and had lost a quantity of water which it retains when dried at lower temperatures; the quantity of water thus loosely combined was found to be three equivalents.

When we look to the constitution of the formula just described, we may probably consider the chlorine to exist as sal-ammoniac, and then combined with an ammonia oxide of platinum, such as is found really to exist; thus the formula may become

$$2\,(Pt\,O_2 + N\,H_3) + Cl\,N\,H_4.$$

It also obviously bears a remarkable relation to the constitution of the fawn-coloured substance, four equivalents of muriatic acid being removed from the latter, and being replaced by one equivalent of ammonia and one of water.

D. When the action of the water of ammonia is still longer continued, this brown matter dissolves and a perfectly colourless liquor is obtained, from which nothing separates by cooling. If, however, a quantity of spirit of wine be added, a copious white, or pale-yellowish white precipitate is produced. This, on drying, aggregates into a mass like coarse meal, which when powdered is nearly quite white.

This substance is not insoluble in water, and dissolves readily in water of ammonia: its solution gives with the oxalic and muriatic acids copious white precipitates, and it dissolves in sulphuric and nitric acids, giving crystalline compounds; when heated it evolves water, ammonia, nitrogen and sal-ammoniac, and leaves metallic platinum.

Its analysis was conducted in the usual manner.

I. 25·357 grains gave 13·043 of platinum, or 50·94 per cent., and yielded by subsequent treatment 18·552 of chloride of silver, corresponding to 18·03 of chlorine in 100.

24·838 grains gave 9·089 of water, equivalent to 3·91 of hydrogen in 100.

22·102 grains gave 10·1259 cubic inches of pure nitrogen at 30 inches barometer and 32° Fahr., equivalent to 14·69 per cent.

II. Another quantity prepared at a different time and of a rather more decidedly yellowish shade than the former was also analysed.

11·406 grains ignited gave 5·741 of platinum, or 50·34 per cent. An accident prevented the determination of the chlorine on that quantity.

17·256 grains, ignited with oxide of copper, gave 6·002 of water, indicating 4·05 per cent. of hydrogen. The residue was treated with nitric acid and nitrate of silver, and gave 12·889 of chloride of silver, equivalent to 18·26 of chlorine in 100.

The experimental results are therefore

	I.	II.
Platinum . . .	50·94	50·34
Chlorine . . .	18·03	18·26
Hydrogen . .	3·91	4·05
Nitrogen . . .	14·69	} 27·35
Oxygen	12·43	
	100·00	100·00

The formula deducible from these analyses is Pt Cl N_2 H_8 O_3. From this the numerical results should be as follows:—

One equivalent of platinum	=	98·8	50·83
One equivalent of chlorine	=	35·4	18·21
Two equivalents of nitrogen	=	28·2	14·51
Eight equivalents of hydrogen	=	8·0	4·11
Three equivalents of oxygen	=	24·0	12·34
		194·4	100·00

By the application of a gentle heat, some water, apparently of hydration, may be separated from the substance, it however does not exceed one equivalent; when dry, therefore, it probably consists of Pt Cl N_2 H_7 O_2.

The relation between this formula and that of the brown substance last described, is exceedingly remarkable, for the above may be considered as consisting of $(Pt\,O_2 + N\,H_3) + Cl\,N\,H_4$, when dry differing from the brown substance in containing twice as much sal-ammoniac; and this relation is supported by the circumstance that by prolonged digestion in a solution of sal-ammoniac, the brown substance may be converted into this white substance.

This body becomes remarkably of interest, inasmuch as the compounds which it forms with acids are found to be identical with the interesting class of salts recently described by Gros, and that this substance is indeed the compound base which Gros considers to be united with the acids in the bodies which he described. The formula which he assigns to the base he hypothetically assumed was Pt Cl N_2 H_6 O, identical with that of the substance just described, with the exception of 2 aq, the separation of which is rendered difficult by the facility with which the body is decomposed. I shall hereafter have occasion to notice the influence which our thus finding Gros's base in the present series must exercise on the views which he put forward, but for the present I shall pass to the additional experimental matter.

E. If, in place of precipitating the ammoniacal solution in the cold by alcohol, it be boiled violently so as to expel all the excess of ammonia, a quantity of the body last described falls down mixed with another of a pale brick-red colour. To obtain this last pure, the solution must be evaporated rapidly with ebullition to perfect dryness. If then any particles of white or yellow still remain, the mass must be mixed up with more water and again boiled until ultimately a pale brick-red, or a lively flesh-red powder remains behind.

The liquor obtained by washing contains much sal-ammoniac.

This powder when heated gives off water, sal-ammoniac and ammonia, and leaves metallic platinum. Boiled in water of ammonia it regenerates Gros's base. When boiled in muriatic acid it produces a yellow solution and a white powder, and by boiling in a solution of sal-ammoniac the muriatic salt of Gros's base.

It was analysed as follows :—

19·077 grains, ignited with carbonate of soda, gave 9·569 of metallic platinum, or 50·11 per cent., and then 22·627 of chloride of silver, equivalent to 29·35 of chlorine in 100.

21·963 grains gave, by ignition with oxide of copper, 6·745 of water, indicating 3·41 of hydrogen per cent.

Another portion dried at a higher temperature and similarly treated, gave 3·34 of hydrogen in 100.

33·478 grains gave 14·8295 cubic inches of pure nitrogen at 30 barometer and 32° Fahr., amounting to 14·21 per cent.

The formula to which this analysis points is $Pt_2\,Cl_3\,N_4\,H_{13}\,O_2$, from which the numbers follow :—

Two equivalents of platinum . .	197·6	50·77
Three equivalents of chlorine. .	106·2	27·29
Four equivalents of nitrogen . .	56·4	14·49
Thirteen equivalents of hydrogen	13·0	3·34
Two equivalents of oxygen . .	16·0	4·11
	389·2	100·00

The relation of this substance to that last described is easily to be seen; it consists in the union of one equivalent of muriatic acid to two equivalents of Gros's base. It would, indeed, upon the principles of that chemist, stand in the singular position of an oxychloride of his compound radical, for it is evident that $(Pt\,Cl\,N_2\,H_6)\,O + (Pt\,Cl\,N_2\,H_6)\,Cl = Pt_2\,Cl_3\,N_4\,H_{12}\,O + 2$ aq. Evidently the manner of formation of this substance is the expulsion of ammonia from Gros's base by the temperature of ebullition and the subsequent combination of the sal-ammoniac of the liquor with the body so evolved. Thus $Pt_2\,Cl_2\,N_4\,H_{12}\,O_2$ losing $N\,H_3$ becomes $Pt_2\,Cl_2\,N_3\,H_9\,O_2$, and by the addition of $N\,H_4\,Cl$ forms the body in question, $Pt_2\,Cl_3\,N_4\,H_{13}\,O_2$.

I have not hitherto stopped to consider the precise manner in which these several bodies are derived from each other, or from the chloride of platinum, and in order to see more clearly their natural relations, it is necessary to make the change already noticed in the commencement of this paper. Ammonia being amidide of hydrogen, and nothing occurring in the chain of reactions now studied to disturb its constitution, I shall for the future look upon the nitrogen as existing in the state of amidogene, and the formulæ already described become then as follows :—

A. $Pt\,Cl_2\,N\,H_3 = Pt\,Cl_2 + Ad\,H$.

B. $Pt_2\,Cl_5\,N_2\,H_{11}\,O_4 = Pt_2\,Cl_5\,Ad_2\,H_7\,O_4$

C. $Pt_2\,Cl\,N_3\,H_{10}\,O_4 = Pt_2\,Cl\,Ad_3\,H_4\,O_4$

D. $Pt\,Cl\,N_2\,H_8\,O_3 = Pt\,Cl\,Ad_2\,H_4\,O_3$

E. $Pt_2\,Cl_3\,N_4\,H_{13}\,O_2 = Pt_2\,Cl_3\,Ad_4\,H_5\,O_2$.

If we were disposed to consider that the principle which was found so remarkably displayed in the instance of the mercurial compounds held with platinum, and that in those instances where oxygen was present it should be looked upon as existing in the state of water, we might find here numerous additions to the class of metallic amidides; thus the body C. should become, doubling the formula above written, $Pt\,Cl_2 + 3\,Pt\,Ad_2 + 8\,H\,O$, and similarly with the others. But it is exceedingly difficult to say when $Pt\,O_2$ and $2\,Ad\,H$ act on one another, whether they unite directly, or whether they mutually decompose, forming $Pt\,Ad_2$ and $2\,H\,O$, which then unite; this difficulty exists in all cases where the water cannot be separated without the substance being completely decomposed. I would postpone for the moment the consideration of this point, and for the time at least look upon the hydrogen as being equally essential with the platinum as a constituent of these bodies.

The formation of the first substance described requires no remark. I find that the same body may be produced by the action of dry ammoniacal gas upon chloride of platinum. There is absorbed about 11 or 12 per cent., indicating one equivalent, $Pt\,Cl_2 + Ad\,H$; but if the current of gas be continued a white powder is obtained, formed by the union of two equivalents of ammonia to one of platinum, and which is identical with the muriatic salt of Gros, of which the formula may be simply written $Pt\,Cl_2 + 2\,Ad\,H$.

It is evident that the body B. cannot be produced directly from the perchloride of platinum, as that does not contain the quantity of chlorine necessary for its constitution, and indeed, if we examine the ammoniacal liquor from the first commencement of the formation of the fawn-coloured substance, it will yield the body D. on the addition of alcohol. I consider therefore these two bodies as being of simultaneous origin, there being formed from

$$3\,Pt\,Cl_2 \text{ with } 4\,Ad\,H \text{ and } 7\,H\,O$$
$$Pt_2\,Cl_5\,Ad_2\,H_7\,O_4 \text{ and } Pt\,Cl\,Ad_2\,H_4\,O_3.$$

From the fawn-coloured substance B., the brown body C. may be simply formed, four equivalents of muriatic acid being removed, and one of ammonia given in their place. This is not equivalent substitution, but it still shows the origin of the body. If, however, the fawn-coloured substance all passed through the brown condition, the quantity of this last generated should, I consider, be much greater than it actually is found to be, and hence I am inclined to consider that

$$\left.\begin{array}{lr} \text{From two atoms of B. . . .} & Pt_4\,Cl_{10}\,Ad_4\,H_{14}\,O_8 \\ \text{And ten atoms of ammonia} & Ad_{10}\,H_{10} \end{array}\right\} Pt_4\,Cl_{10}\,Ad_{14}\,H_{24}\,O_8$$

there are formed

$$\left.\begin{array}{lr} \text{One atom of C. . . . . . .} & Pt\,Cl\,Ad_3\,H_4\,O_4 \\ \text{Two of Gros's base dry . .} & Pt_2\,Cl_2\,Ad_4\,H_8\,O_4 \\ \text{Seven of sal-ammoniac . . .} & Cl_7\,Ad_7\,H_{14} \end{array}\right\} Pt_4\,Cl_{10}\,Ad_{14}\,H_{24}\,O_8.$$

One source of the origin of the body D. (GROS's base) is thus explained, but it may be produced directly from the fawn-coloured substance as follows :—

$$\left.\begin{array}{lr} \text{One atom of B. . . . . . .} & Pt_2\,Cl_5\,Ad_2\,H_7\,O_4 \\ \text{Five of ammonia . . . . .} & Ad_5\,H_5 \end{array}\right\} Pt_2\,Cl_5\,Ad_7\,H_{12}\,O_4$$

produce

$$\left.\begin{array}{lr} \text{Two atoms of GROS's base . .} & Pt_2\,Cl_2\,Ad_4\,H_6\,O_4 \\ \text{Three atoms of sal-ammoniac.} & Cl_3\,Ad_3\,H_6 \end{array}\right\} Pt_2\,Cl_5\,Ad_7\,H_{12}\,O_4.$$

In this case no brown substance (C.) should be formed.

The origin of the body E. from GROS's base has been already noticed.

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KEPT BY THE ASSISTANT SECRETARY,

AT THE APARTMENTS OF THE

ROYAL SOCIETY,

BY ORDER OF

THE PRESIDENT AND COUNCIL.

OBSERVANDA.

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——————— above the mean level of the sea ....97 feet.
Height of the receiver of the Rain Gauge above the court of Somerset House ..79 feet.
The External Thermometer is 2 feet higher than the Barometer Cistern.
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1842.	9 o'clock, A.M. Barometer uncorrected. Flint Glass.	9 o'clock, A.M. Barometer uncorrected. Crown Glass.	9 o'clock, A.M. Att. Ther.	3 o'clock, P.M. Barometer uncorrected. Flint Glass.	3 o'clock, P.M. Barometer uncorrected. Crown Glass.	3 o'clock, P.M. Att. Ther.	Dew Point at 9 A.M. deg. Fahr.	Diff. of Wet and Dry Bulb Ther.	External Thermometers. Fahrenheit. 9 A.M.	External Thermometers. Fahrenheit. 3 P.M.	External Thermometers. Self-registering Lowest	External Thermometers. Self-registering Highest	Rain in inches. Read off at 9 A.M.	Direction of the Wind at 9 A.M.	REMARKS.
JANUARY															
S 1	30.230	30.222	41.0	30.208	30.200	41.6	34	01.8	36.3	39.3	35.0	42.0		SE	Light clouds and wind throughout the day. Evening, Fine & starlight—sharp frost.
☉ 2	30.192	30.184	39.2	30.120	30.112	39.3	33	02.2	34.7	37.7	33.3	40.7		N	Light fog and wind—sharp frost throughout the day. Evening, Overcast—slight rain.
M 3	30.022	30.016	38.0	30.002	29.994	37.7	32	01.6	34.2	33.7	33.0	38.8		N	Fine—light clouds and fog throughout the day. Ev. Fine & starlight [—lt. fog.
T 4	29.944	29.936	34.3	29.982	29.974	35.3	28	00.9	30.3	33.0	28.2	34.5		N	Fine—light clouds—brisk wind—sharp frost throughout the day. Ev. Early part, snow—after part, starlight—sharp frost.
W 5	30.050	30.044	35.0	30.048	30.042	36.3	30	*frozen*	32.7	36.3	30.6	34.0		W	A.M. Lt. clds. & wind. P.M. Cloudy—lt. wind. Ev. Ovct.—lt. snow.
T 6	30.180	30.172	36.3	30.224	30.216	37.8	36	01.5	34.7	36.8	32.9	37.3		NW	A.M. Cloudy—brisk wind—thaw. P.M. Fine—light clouds—continued thaw. Evening, Cloudy—sharp frost.
F 7	30.490	30.482	35.5	30.468	30.460	35.9	29	*frozen*	29.5	34.3	29.6	37.7		N	Fine—light clouds and wind—sharp frost throughout the day. Ev. Overcast—light snow—sharp frost.
S 8	30.496	30.488	34.8	30.416	30.408	34.6	26	*ditto*	31.2	32.0	29.5	35.2		N	Fine—lt. clouds & wind—sharp frost throughout the day. Ev. Overcast—sharp frost.
☉ 9	30.238	30.230	32.6	30.112	30.104	32.6	25	*ditto*	29.2	29.8	28.8	34.0		N	A.M. Lt. fog & wind—sharp frost. P.M. Ovct.—lt. snow—sharp frost. [Ev. Lt. fog—sharp frost.
M10	30.128	30.120	32.6	30.068	30.060	33.0	23	*ditto*	30.3	31.7	28.8	31.0		N	Light fog & wind—sharp frost throughout the day. Ev. Overcast—sharp frost.
○ T11	30.002	29.996	34.0	30.014	30.006	35.0	30	01.9	33.8	35.3	30.4	34.5		S	A.M. Hazy—light wind—snow early. P.M. Cloudy—light wind & thaw. Evening, Cloudy—light snow.
W12	30.066	30.058	35.0	30.044	30.036	36.7	30	02.0	33.7	35.8	32.8	36.2	.075*	S	A.M. Cloudy—light wind. P.M. Fine—light clouds and wind. Evening, Fine and starlight—frost.
T13	29.872	29.868	36.0	29.812	29.804	36.6	32	00.5	33.0	32.3	33.0	38.0		SSE	Overcast—snow—light wind throughout the day. Ev. The same.
F14	29.514	29.508	36.3	29.598	29.590	38.0	34	01.8	36.7	35.3	30.2	37.3	.091*	S	A.M. Overcast—light wind and thaw. P.M. Fine—light clouds—continued thaw. Evening, Overcast—frost.
S15	29.948	29.942	37.3	29.976	29.968	38.0	32	02.0	34.2	38.2	32.5	37.7		S	Light fog and wind throughout the day. Ev. Fine and starlight.
☉16	29.782	29.774	37.5	29.770	29.766	39.0	34	01.8	37.7	41.7	33.0	38.2	.022	SSE	A.M. Overcast—slight rain and wind. P.M. Fine—light clouds. Ev. Early part, fine and moonlight—after part, ovct.—deposition.
M17	30.072	30.064	37.8	30.156	30.148	40.0	34	02.2	36.7	41.8	34.3	42.4		SW	Fine—light clouds & wind throughout the day. Evening, Fine and starlight—light fog.
T18	30.380	30.372	37.3	30.416	30.408	37.4	32	01.4	30.6	33.3	30.3	42.6		W	Light fog and wind, with sharp frost throughout the day. Evening, Overcast—light fog.
W19	30.480	30.472	37.8	30.398	30.390	38.0	33	01.4	33.7	34.3	30.0	38.2		W	Thick fog—thaw throughout the day. Ev. Thick fog—sharp frost.
T20	30.174	30.166	36.3	30.094	30.086	37.4	33	02.3	33.4	35.4	29.3	34.6		S	Overcast—light fog and wind throughout the day. Ev. The same.
F21	30.044	30.036	38.0	30.040	30.032	38.0	33	01.6	34.3	35.2	33.2	35.3		N	Light fog and wind throughout the day. Evening the same.
S 22	29.880	29.872	37.5	29.622	29.614	37.8	32	02.5	34.3	36.0	33.8	35.3		E	Lightly overcast—light snow, wind, and frost, throughout the day. Evening, Overcast—light rain.
☉23	29.240	29.234	37.3	29.362	29.356	38.0	32	02.2	32.4	35.2	32.3	38.8	.119	W	Fine—light clouds and wind—sharp frost throughout the day. Ev. Fine and starlight.
M24	29.846	29.840	33.8	29.828	29.820	33.9	27	00.8	28.7	32.7	27.3	36.2	.	W	Fine—light fog—sharp frost throughout the day. Evening, Cloudy.
T 25	29.348	29.342	34.6	29.560	29.552	37.2	32	01.4	35.3	41.5	29.3	35.6	.091	W	A.M. Snow early—overcast—light rain & wind. P.M. Fine—light clouds. Evening, The same.
● W26	29.446	29.440	36.7	29.112	29.104	39.3	33	01.8	39.3	44.0	33.0	41.8	.041	SE	A.M. Overcast—light rain—very high wind. P.M. Fine—light clouds—high wind. Evening, Moonlight—light clouds.
T 27	29.678	29.670	39.6	29.786	29.778	40.8	34	02.8	38.4	43.8	37.6	44.6	.133	S var.	Fine—lt. clouds & wind throughout the day. Ev. Fine & moonlight.
F 28	29.850	29.846	40.0	29.886	29.878	40.8	35	01.5	36.4	41.7	36.0	44.2		W	Fine—light clouds & wind throughout the day. Ev. Fine & starlight.
S 29	29.990	29.982	39.0	30.036	30.024	40.0	35	01.8	36.0	41.5	33.2	42.3		W	A.M. Overcast—light fog and wind, with very slight rain. P.M. Overcast—light fog. Evening the same.
☉30	30.262	30.254	39.8	30.260	30.254	41.5	35	01.7	36.7	39.0	35.6	41.7		NW	Light fog and wind throughout the day. Ev. Overcast—light fog.
M31	30.134	30.126	40.0	30.040	30.032	41.8	37	02.2	40.7	46.4	36.5	41.2		S	Overcast—light wind throughout the day. Ev. Overcast—light rain.
MEAN.	29.999	29.992	36.8	29.983	29.975	37.7	32	01.7	34.2	36.9	32.0	38.1	Sum. .572 *Melted snow.]		Mean Barometer corrected .... 9 A.M. 3 P.M. F. 29.981 .. 29.963 C. 29.973 .. 29.954
FEBRUARY															
T 1	30.140	30.134	42.3	30.156	30.148	43.7	42	02.5	39.5	45.3	37.8	47.0	.166	W	Fine—lt. clouds and wind throughout the day. Ev. Overcast—lt. fog.
W 2	30.198	30.190	42.8	30.202	30.196	44.8	38	02.5	41.7	48.7	38.0	45.7		SW	A.M. Light fog & wind. P.M. Cloudy—lt. wind. Ev. Ovct.—lt. fog.
T 3	30.436	30.428	45.5	30.432	30.424	46.0	41	02.3	43.8	45.4	41.7	49.2		NW	A.M. Light fog and wind. P.M. Cloudy—lt. wind. Ev. The like.
F 4	30.480	30.472	45.3	30.424	30.416	45.0	40	02.2	39.8	36.3	40.3	46.3		NE	A.M. Cloudy—light wind. P.M. Fine—light clouds and wind. Evening, Overcast—light fog.
S 5	30.286	30.278	40.7	30.204	30.196	40.6	35	02.3	35.7	35.7	33.3	40.0		ENE	A.M. Cloudy—light wind—sharp frost. P.M. Fine—light clouds. Evening, Fine and starlight—frosty.
☉ 6	30.118	30.110	37.8	29.996	29.990	39.0	29	02.9	32.8	37.6	32.0	35.7		E	Lightly cloudy—light wind throughout the day. Evening, Fine and starlight—light fog.
M 7	29.724	29.716	36.8	29.722	29.714	38.6	33	01.4	35.2	38.5	33.0	37.6	.033	ENE	A.M. Overcast—light rain—snow and fog. P.M. Cloudy—light wind. [Ev. Overcast.
T 8	29.828	29.820	38.0	29.812	29.804	39.0	33	01.1	34.8	43.7	33.0	40.6	.094	NE	Overcast—light rain and wind throughout the day. Ev. Light fog.
W 9	29.812	29.804	40.9	29.744	29.736	42.7	38	01.2	40.8	48.3	35.2	45.0	.063	S	Fine—light clouds and wind throughout the day. Ev. Overcast.
○ T10	29.946	29.938	43.8	30.000	29.992	45.8	41	01.4	45.7	49.8	41.2	49.0		S	Cloudy—light wind throughout the day. Ev. Cloudy—Brisk wind.
F 11	30.026	30.018	48.0	30.022	30.014	50.0	46	02.3	47.3	51.4	45.8	50.3		S	Cloudy—high wind throughout the day. Ev. Overcast—light rain—high wind.
S 12	30.072	30.064	49.5	30.040	30.032	51.0	46	02.0	50.2	51.3	47.4	52.2	.094	S	A.M. Dark heavy clouds—high wind. P.M. Overcast—light rain—high wind. Evening, Overcast.
☉13	30.220	30.214	49.0	30.056	30.050	50.0	43	00.5	44.2	50.2	42.5	53.0	.009	SSE	A.M. Overcast—light fog and wind. P.M. Overcast—light rain—high wind. Evening, Fine and starlight.
M 14	30.456	30.448	46.2	30.492	30.486	47.8	41	02.2	40.3	49.2	38.5	50.7	.061	W	Fine—light clouds and wind throughout the day. Evening, Cloudy.
T 15	30.500	30.492	47.6	30.478	30.470	49.6	44	02.8	46.8	51.2	40.3	49.7		S	A.M. Cloudy—light wind. P.M. Fine—light clouds and wind. Evening, Fine and starlight.
W16	30.546	30.538	47.6	30.518	30.510	48.2	43	02.0	46.3	48.7	44.8	51.6		W	Cloudy—light wind throughout the day. Evening, The like.
T 17	30.410	30.402	47.2	30.330	30.322	48.6	43	01.9	44.3	47.3	43.7	49.2		S	A.M. Light fog and wind. P.M. Overcast—light wind. Evening, Fine and starlight.
F 18	30.374	30.366	44.8	30.370	30.362	45.5	38	02.8	36.8	43.6	36.0	48.2		S	A.M. Overcast—light wind. P.M. Fine—lt. clouds. Ev. Thick fog.
S 19	30.402	30.394	42.4	30.304	30.296	44.2	39	01.8	34.7	43.3	33.3	43.7		SW	A.M. Thick fog. P.M. Fine—light clouds. Ev. Starlight—light fog.
☉20	30.054	30.046	42.2	29.966	29.958	42.0	37	02.0	35.3	36.3	35.0	45.0		S	A.M. Overcast—very slight rain. P.M. Overcast—light wind. Evening, The like.
M21	29.782	29.776	41.2	29.690	29.684	43.3	36	02.4	39.7	46.7	35.0	40.0		SE	A.M. Cloudy—brisk wind. P.M. Overcast—light rain. Ev. The liko.
T 22	29.756	29.750	42.4	29.676	29.670	46.0	39	02.0	41.8	48.2	38.8	47.8	.161	E	A.M. Cloudy—light wind. P.M. Fine—light clouds and wind. Evening, Overcast.
W23	29.444	29.436	44.9	29.304	29.300	47.2	42	02.7	44.8	48.4	42.0	48.8		SSE	A.M. Cloudy—light wind. P.M. Fine—lt. clouds & wind. Evening, Overcast—light rain.
T 24	29.152	29.148	46.3	29.114	29.110	48.4	41	02.3	41.9	47.7	41.8	49.5	.059	S	Cloudy—light wind throughout the day. Evening, The like.
● F 25	29.216	29.208	46.0	29.310	29.304	47.0	41	02.0	39.3	44.3	36.3	48.0	.130	W	A.M. Cloudy—light rain and wind. P.M. Fine—light clouds, with showers. Evening, Fine and moonlight.
S 26	29.400	29.392	42.6	29.466	29.460	44.6	36	02.6	39.2	45.7	35.0	45.3	.052	SE	A.M. Cloudy—light wind—rain early. P.M. Fine—nearly cloudless. Evening, Fine and moonlight.
☉27	29.550	29.544	42.3	29.380	29.374	43.2	36	02.9	40.5	42.6	35.2	46.0	.133	S	Overcast—light rain—hrisk wind nearly the whole of the day. Ev. [Cloudy.
M 28	29.622	29.616	42.5	29.636	29.630	45.4	38	02.6	41.7	47.7	39.0	43.6	.291	S	A.M. Fine—light clouds and wind. P.M. Cloudy—light wind. Evening, Light rain—high wind.
MEAN.	29.998	29.991	43.8	29.958	29.952	45.3	39	02.1	40.9	45.5	38.4	46.4	Sum. 1.346		Mean Barometer corrected .... 9 A.M. 3 P.M. F. 29.961 .. 29 917 C. 29.952 .. 29.910

METEOROLOGICAL JOURNAL FOR MARCH AND APRIL, 1842.

1842.	9 o'clock, A.M. Barometer uncorrected. Flint Glass.	9 o'clock, A.M. Barometer uncorrected. Crown Glass.	9 o'clock, A.M. Att. Ther.	3 o'clock, P.M. Barometer uncorrected. Flint Glass.	3 o'clock, P.M. Barometer uncorrected. Crown Glass.	3 o'clock, P.M. Att. Ther.	Dew Point at 9 A.M. deg. Fahr.	Diff. of Wet and Dry Bulb Thermometer.	External Thermometers. Fahrenheit. A.M.	External Thermometers. Fahrenheit. 3 P.M.	External Thermometers. Self-registering. Lowest	External Thermometers. Self-registering. Highest	Rain in inches. Read off at 9 A.M.	Direction of the Wind at 9 A.M.	REMARKS.
MARCH															
T 1	29.236	29.230	48.0	29.380	29.372	50.7	46	01.5	49.8	48.6	42.0	50.5	.047	S	A.M. Overcast—slight rain—light wind. P.M. Fine—light clouds. Evening, Fine and starlight—light clouds.
W 2	29.770	29.762	45.4	29.640	29.636	48.5	40	03.0	43.7	50.3	37.8	51.0		S	Overcast—brisk wind—light rain nearly the whole of the day. Evening, The same.
T 3	29.916	29.908	50.2	29.906	29.898	52.2	47	02.9	52.3	55.7	43.7	52.6	.402	SSW	A.M. Cloudy—brisk wind. P.M. Fine—light clouds. Ev. Cloudy.
F 4	30.008	30.000	50.6	29.966	29.958	51.7	45	03.3	45.3	49.0	43.8	55.8		SW	Cloudy—light wind throughout the day. Evening, Overcast—very slight rain.
S 5	30.042	30.036	48.3	30.082	30.074	50.3	42	02.1	41.3	49.8	39.0	50.6		S	Fine—light clouds throughout the day. Evening, Fine & starlight.
☉ 6	30.010	30.002	47.4	29.888	29.882	48.2	41	02.9	42.0	49.5	39.2	52.2		SSW	Fine—nearly cloudless throughout the day. Ev. Fine and starlight.
M 7	29.750	29.742	45.7	29.642	29.636	48.8	40	03.0	44.3	50.3	39.0	51.0		S	Cldy.—lt. wind throughout the day. Ev. Overcast—very slight rain.
T 8	29.528	29.520	50.6	29.504	29.498	51.7	46	03.4	51.5	53.5	44.3	51.8		S	A.M. Cloudy—brisk wind—high wind throughout the night. P.M. Fine—light clouds. Evening, Overcast—light rain.
W 9	29.660	29.652	49.5	29.650	29.644	49.8	42	03.4	43.3	46.8	39.0	54.6	.150	S	A.M. Fine—light clouds and wind with showers. P.M. Cloudy. Evening, Overcast—light rain—high wind.
T 10	29.574	29.568	46.5	29.830	29.824	47.9	40	04.3	41.5	46.8	38.6	49.4	.455	W	A.M. Cloudy—very high wind, as also throughout the night. P.M. Fine—light clouds—brisk wind. Evening, Fine and starlight.
F 11	30.040	30.032	46.2	29.900	29.894	48.5	40	03.4	45.3	51.0	40.0	48.6		S	Overcast—light wind throughout the day. Evening, The same.
○ S 12	30.094	30.086	48.8	30.050	30.042	51.0	42	03.5	44.3	54.3	41.3	53.6		W	Fine—light clouds and wind throughout the day. Ev. Fine & starlight.
☉ 13	29.940	29.934	50.2	30.086	30.082	51.0	44	05.0	46.3	51.5	43.7	56.0	.094	W	A.M. Fine—broken clouds—light wind—very high wind, and light rain early. P.M. Cloudy—brisk wind. Evening, Light fog.
M 14	30.276	30.268	48.3	30.308	30.300	50.4	43	03.4	45.4	49.8	44.2	51.7	.022	S	Overcast—lt. wind, with occasional slight rain throughout the day. Evening, Overcast.
T 15	30.398	30.392	50.0	30.384	30.376	51.5	46	02.3	49.5	54.0	45.3	50.8		S	Overcast—light wind throughout the day—very slight rain early. Ev. [Light fog.
W 16	30.360	30.352	52.0	30.264	30.256	52.8	49	02.7	51.3	51.8	49.8	54.6		S	Overcast—light wind throughout the day. Evening, Overcast—very slight rain.
T 17	30.188	30.180	52.4	30.074	30.066	54.2	48	04.4	50.3	53.8	47.4	52.7		W	Cloudy—lt. wind throughout the day. Ev. Overcast—light rain.
F 18	29.792	29.786	54.3	29.714	29.706	54.0	48	05.0	48.7	49.7	45.7	55.3	.041	W	Fine—lt. clouds & wind throughout the day—high wind throughout the night. Evening, Slight rain.
S 19	29.558	29.552	52.3	29.420	29.414	50.3	40	05.1	43.6	45.3	39.0	52.3		W	A.M. Fine—light clouds—brisk wind. P.M. Ovct.—brisk wind. Ev. [Light rain.
☉ 20	29.298	29.292	47.9	29.464	29.456	49.0	42	03.8	41.7	47.2	41.4	46.7	.080	NW	A.M. Overcast—light rain and wind. P.M. Fine—light clouds and wind. Evening, Overcast—light rain.
M 21	29.890	29.884	47.8	30.018	30.010	47.7	39	03.2	41.7	45.0	39.4	48.0	.105	NW	A.M. Fine—light clouds—brisk wind. P.M. Light showers—brisk wind. Evening, Fine and moonlight.
T 22	30.158	30.150	47.0	30.032	30.026	47.8	36	03.5	39.5	44.7	36.9	46.4	.091	NW	A.M. Fine—lt. clouds & wind. P.M. Cloudy—brisk windy. Ev. Ovct. [brisk wind.
W 23	30.124	30.118	49.6	30.130	30.122	45.0	35	04.7	39.5	37.7	34.3	45.2	.094	N	A.M. Fine—light clouds—brisk wind—light snow. P.M. Fine—light clouds—brisk wind—light snow. Ev. Fine and starlight.
T 24	30.240	30.232	41.6	30.206	30.198	43.4	35	03.5	37.8	43.7	33.6	43.3	.025	N	Overcast—light wind throughout the day. Evening, Slight rain.
F 25	30.128	30.120	44.8	29.976	29.968	47.8	39	02.3	44.7	52.3	37.9	45.2		SW	Cloudy—light wind throughout the day. Evening, Overcast.
● S 26	29.636	29.630	51.5	29.592	29.584	48.3	40	04.2	44.8	48.2	39.8	53.4	.086	W	A.M. Fine—light clouds and wind—high wind—light rain throughout the night. P.M. Fine—light showers. Evening, Cloudy.
☉ 27	29.774	29.766	47.6	29.782	29.776	48.0	40	04.4	43.3	50.2	36.0	49.0		W	A.M. Overcast—light wind. P.M. Fine—light clouds and wind. Evening, Very slight rain.
M 28	29.720	29.712	47.0	29.754	29.746	51.0	43	02.7	50.3	57.7	43.0	50.8		W	A.M. Overcast—lt. wind. P.M. Cloudy—light wind. Ev. The same.
T 29	29.912	29.904	52.3	29.960	29.952	53.3	46	03.8	50.2	56.8	49.2	58.5		W	Cloudy—light wind throughout the day. Evening, The same.
W 30	29.896	29.888	53.0	29.836	29.828	54.7	48	03.0	50.7	55.7	49.2	57.4	.016	S	A.M. Overcast—light showers. P.M. Fine—light clouds, with occasional showers. Evening, Overcast.
T 31	29.780	29.774	51.6	29.592	29.586	53.2	47	02.5	48.8	55.0	45.6	57.4	.069	SSE	A.M. Overcast—slight rain—brisk wind. P.M. Overcast—very slight rain. Evening, Overcast—light rain and wind.
MEAN.	29.893	29.886	49.0	29.872	29.865	50.1	42	03.4	45.6	50.2	41.6	51.5	Sum. 1.777		Mean Barometer corrected .... 9 A.M. 3 P.M. F. 29.842 .. 29.819 C. 29.834 .. 29.811
APRIL															
F 1	29.340	29.334	52.8	29.328	29.324	53.0	45	03.9	45.0	44.7	43.4	57.6	.172	S	A.M. Cloudy—lt. showers—brisk wind—very high wind throughout the night. P.M. Fine—lt. clouds—hail & rain. Ev. Fine & starlight.
S 2	29.606	29.600	49.9	29.702	29.696	49.8	42	02.9	41.8	43.8	38.0	48.6	.088	NW	A.M. Overcast—light brisk wind, with showers. P.M. Cloudy—brisk wind. Evening, Fine and starlight.
☉ 3	29.836	29.830	53.7	29.916	29.910	46.5	36	04.1	38.4	44.3	34.2	46.5		NW	A.M. Cloudy—light brisk wind. P.M. Heavy clouds—brisk wind. Evening, Cloudy—slight rain.
M 4	30.188	30.180	44.2	30.244	30.236	46.0	36	04.5	40.7	44.5	37.0	46.0		NW	Cloudy—brisk wind throughout the day. Evening, The same.
T 5	30.392	30.384	50.0	30.334	30.326	46.6	35	05.2	41.7	46.5	36.5	46.7		N	A.M. Cloudy—lt. wind. P.M. Fine—lt. clouds. Ev. Fine & starlight.
W 6	30.200	30.194	49.0	30.046	30.038	46.8	36	04.7	42.4	50.0	35.3	47.5		NE	Fine—lt. clouds & wind throughout the day. Ev. Fine & starlight.
T 7	29.862	29.854	45.2	29.824	29.816	48.3	42	02.7	43.7	56.3	39.6	52.0		N	A.M. Overcast—brisk wind. P.M. Fine—light clouds. Evening, Fine and starlight.
F 8	30.094	30.086	48.0	30.144	30.136	49.7	43	03.4	44.8	51.3	39.4	56.9		NE	A.M. Cloudy—light brisk wind. P.M. Fine—nearly cloudless. Evening, Fine and starlight.
S 9	30.358	30.350	52.7	30.332	30.324	47.4	36	05.3	44.2	45.3	37.0	52.7		E	A.M. Cloudy—light wind. P.M. Fine—light clouds and wind. Evening, Cloudy.
◯ ☉ 10	30.388	30.380	43.8	30.318	30.312	46.0	33	03.0	43.2	45.9	37.0	46.6		E	A.M. Cloudy—light wind. P.M. Overcast—lt. wind. Ev. Cloudy.
M 11	30.248	30.240	48.9	30.164	30.158	46.8	37	05.1	43.7	46.3	36.7	46.3		NE	A.M. Cloudy—brisk wind. P.M. Fine—light clouds & wind, with hail shower. Evening, Overcast.
T 12	30.118	30.112	46.0	30.032	30.024	45.2	33	06.2	42.0	43.3	37.6	46.7	.050	NE	A.M. Cloudy—brisk wind. P.M. Overcast—lt. snow. Ev. Overcast.
W 13	29.990	29.982	42.3	29.960	29.954	44.7	36	02.8	39.2	42.7	37.8	44.4		N	Cloudy—brisk wind throughout the day—slight rain early. Evening, Overcast—light rain.
T 14	29.932	29.926	42.5	29.954	29.948	45.2	38	02.6	41.2	47.2	37.8	43.6	.063	N	A.M. Overcast—light brisk wind. P.M. Overcast—hail and rain—brisk wind. Evening, Overcast.
F 15	30.084	30.076	46.0	30.068	30.060	47.0	39	04.5	44.3	48.4	40.3	47.6		N	Cloudy—brisk wind throughout the day. Ev. Fine and moonlight.
S 16	30.144	30.136	50.6	30.124	30.116	46.9	38	04.6	44.6	47.4	39.5	49.0		NE	A.M. Cloudy—brisk wind. P.M. Fine—lt. clouds—brisk wind. Ev. Fine and starlight.
☉ 17	30.206	30.198	44.0	30.176	30.172	46.0	40	04.0	44.4	46.8	37.8	48.7		N	Overcast—brisk wind throughout the day. Evening, Overcast—very slight rain.
M 18	30.210	30.202	46.9	30.194	30.186	47.6	40	03.6	44.2	47.3	42.0	47.4		N	Overcast—light wind throughout the day. Evening, The same.
T 19	30.232	30.224	45.5	30.178	30.170	47.6	40	02.9	42.3	51.3	41.3	47.8		N	A.M. Overcast—light wind. P.M. Fine—nearly cloudless. Ev. Fine and starlight.
W 20	30.182	30.176	53.3	30.140	30.132	50.3	43	04.7	49.4	58.7	38.7	51.8		N	A.M. Fine—light clouds and wind. P.M. Fine and cloudless. Evening, Fine and starlight.
T 21	30.182	30.176	57.6	30.108	30.100	51.7	44	03.1	46.8	55.7	41.3	59.5		ENE	A.M. Cloudy—lt. brisk wind. P.M. Fine—lt. clouds. Ev. Overcast.
F 22	30.022	30.014	50.3	29.944	29.936	53.0	44	02.1	46.8	60.7	45.0	56.5		NE	A.M. Overcast—lt. brisk wind. P.M. Fine & cloudless. Ev. Cloudy.
S 23	29.942	29.936	60.0	29.914	29.906	57.0	50	04.3	54.3	67.3	47.0	61.3		NNW	Fine—lt. clouds and wind throughout the day. Ev. Fine & moonlight.
● ☉ 24	29.974	29.966	63.0	29.946	29.942	59.0	54	03.8	60.5	61.5	52.0	68.6		N	A.M. Fine—light clouds. P.M. at ½ past 2, heavy thunder & forked lightning, with heavy rain. Ev. Fine and starlight.
M 25	30.080	30.072	58.8	30.068	30.060	60.3	54	05.2	57.8	66.5	49.0	69.3	.097	E	Fine—lt. clouds & wind throughout the day. Ev. Fine & moonlight.
T 26	30.114	30.108	71.3	30.076	30.068	59.0	52	07.7	56.7	59.3	47.4	67.5		NE	Fine—nearly cloudless throughout the day. Ev. Fine and starlight.
W 27	30.048	30.040	67.8	30.012	30.004	57.4	46	08.3	54.3	58.7	44.5	62.3		NE	Fine—nearly cloudless—light wind throughout the day. Evening, Fine and starlight.
T 28	30.100	30.092	62.0	30.080	30.072	58.3	48	05.8	54.7	65.2	45.8	59.4		N	Fine—lt. clouds & wind throughout the day. Ev. Fine & starlight.
F 29	30.088	30.082	62.3	30.008	30.000	58.8	46	07.6	55.3	63.0	45.7	66.0		NE	A.M. Fine—lt. clouds & wind. P.M. Fine & cloudless. Ev. Cloudy.
S 30	29.882	29.876	69.7	29.822	29.814	60.3	51	06.9	57.7	68.7	47.6	64.6		ENE	Fine—nearly cloudless—light wind throughout the day. Evening, Fine and starlight.
MEAN.	30.068	30.061	52.6	30.039	30.031	50.7	42	04.5	46.9	52.6	41.1	53.8	Sum. .470		Mean Barometer corrected .... 9 A.M. 3 P.M. F 30.007 .. 29.983 C. 29.999 .. 29.974

METEOROLOGICAL JOURNAL FOR MAY AND JUNE, 1842.

1842.	9 o'clock, A.M. Barometer uncorrected. Flint Glass.	9 o'clock, A.M. Barometer uncorrected. Crown Glass.	9 o'clock, A.M. Att. Ther.	3 o'clock, P.M. Barometer uncorrected. Flint Glass.	3 o'clock, P.M. Barometer uncorrected. Crown Glass.	3 o'clock, P.M. Att. Ther.	Dew Point at 9 A.M., deg. Fahr.	Diff. of Wet and Dry Bulb Thermometer.	External Thermometers. Fahrenheit. 9 A.M.	External Thermometers. Fahrenheit. 3 P.M.	External Thermometers. Self-registering. Lowest	External Thermometers. Self-registering. Highest	Rain in Inches. Read off at 9 A.M.	Direction of the Wind at 9 A.M.	REMARKS.
☉ 1	30.002	29.996	70.4	30.004	29.998	61.0	50	08.0	59.3	66.3	47.6	69.6		N	Fine—light clouds—brisk wind throughout the day. Evening, Fine and starlight.
M 2	30.084	30.076	62.4	30.032	30.024	60.0	50	09.3	57.3	61.3	47.8	67.7		NE	Fine and cloudless—brisk wind throughout the day. Evening, Fine and starlight.
T 3	29.986	29.978	61.3	29.892	29.884	58.8	43	06.2	50.2	65.4	42.0	62.5		WNW	A.M. Fine—light clouds and wind. P.M. Cloudy—light wind. Evening, Overcast—light rain.
W 4	29.956	29.948	63.0	29.810	29.802	60.4	49	06.0	53.7	61.2	49.3	66.4	.069	W	A.M. Cloudy—lt. wind. P.M. Fine—light clouds & wind. Ev. Fine [& starlight.
T 5	29.904	29.896	64.0	29.770	29.762	60.3	50	06.8	56.8	58.2	47.6	62.0		S	Cloudy—light wind throughout the day. Ev. Overcast—light rain.
F 6	29.438	29.434	64.3	29.414	29.406	60.7	52	05.7	55.3	56.0	50.6	61.8	.122	S	Dark heavy clouds, with showers throughout the day. Ev. Overcast.
S 7	29.340	29.332	56.8	29.268	29.260	59.0	51	04.8	51.7	60.3	49.0	62.3	.213	S	A.M. Overcast—light rain—high wind. P.M. Cloudy—brisk wind. Evening, Overcast.
☉ 8	29.416	29.408	60.2	29.560	29.552	58.3	50	05.5	54.2	56.8	48.4	62.0	.241	W var.	Dark heavy clouds—brisk wind, with showers throughout the day. Evening, Fine and starlight.
M 9	29.948	29.940	61.7	30.020	30.012	57.8	45	06.1	51.3	52.7	46.4	61.6	.130	W	Cloudy—light wind, with showers throughout the day. Evening, Thunder and lightning, with rain.
○ T 10	30.218	30.210	63.3	30.160	30.152	57.4	45	06.5	52.0	58.7	41.8	60.5	.061	W	Cloudy—light wind throughout the day. Evening, Fine & starlight.
W 11	30.006	30.000	66.0	29.910	29.902	58.0	47	07.8	57.3	61.7	46.2	61.0		E	Fine—light clouds and wind throughout the day. Evening, Cloudy.
T 12	29.948	29.942	54.3	29.976	29.968	55.0	47	03.0	46.3	50.3	46.0	64.8	.130	NW	Overcast—light rain and wind throughout the day. Ev. Overcast.
F 13	30.082	30.074	60.8	30.078	30.070	58.5	48	05.4	54.7	63.7	47.6	57.0	.225	S	A.M. Cloudy—light wind. P.M. Fine and cloudless. Ev. Cloudy.
S 14	30.200	30.194	59.3	30.208	30.200	58.7	48	04.3	53.2	63.2	48.4	64.2	.025	W	Overcast—light wind throughout the day. Evening, Overcast.
MAY ☉ 15	30.408	30.400	58.6	30.390	30.384	60.0	54	04.5	55.7	63.5	48.0	64.4		E	A.M. Cloudy—light wind. P.M. Fine—light clouds and wind. Evening, Overcast.
M 16	30.436	30.428	57.8	30.374	30.366	61.3	54	05.2	57.8	65.3	48.7	64.3		N	Cloudy—light wind throughout the day. Evening, Fine & starlight.
T 17	30.314	30.306	56.6	30.244	30.236	59.8	51	04.3	52.8	57.7	45.7	66.5		N	Cloudy—light wind throughout the day! Evening, Fine & moonlight.
W 18	30.072	30.064	55.5	29.996	29.988	57.4	50	04.0	50.7	56.4	47.8	60.3	.022	N	A.M. Overcast—very fine rain. P.M. Overcast—light wind. Ev. Fine and starlight.
T 19	29.834	29.828	57.6	29.754	29.748	57.9	48	04.4	53.8	57.5	47.6	57.0		SE	A.M. Cloudy—light wind. P.M. Overcast—slight rain. Evening, Fine and starlight.
F 20	29.706	29.700	63.4	29.704	29.696	59.0	50	06.1	57.0	58.3	47.0	70.3		S var.	Cloudy—light wind throughout the day. Evening, The same.
S 21	29.730	29.722	59.2	29.732	29.726	59.3	49	06.2	56.7	57.7	51.3	62.3		SE	A.M. Cloudy—high wind, with slight showers. P.M. Dark heavy clouds. Evening, Overcast—light showers.
☉ 22	29.798	29.792	60.6	29.756	29.750	60.2	51	06.2	57.8	61.6	49.8	69.0	.022	SE	A.M. Cloudy—light wind. P.M. Fine—light clouds and wind. Evening, Cloudy—slight rain—rainbow.
M 23	29.854	29.848	66.8	29.886	29.878	61.6	50	06.7	57.2	61.5	51.4	75.3		SSE	A.M. Cloudy—light wind. P.M. Fine—light clouds. Ev. Cloudy.
● T 24	29.882	29.874	57.9	29.818	29.810	60.0	51	04.3	53.3	59.7	52.7	64.6		SE	A.M. Overcast—light rain. E.M. Cloudy—light wind. Evening, Fine and moonlight.
W 25	29.904	29.898	60.9	29.896	29.888	60.4	51	05.5	55.7	60.7	47.6	60.0	.261	S	Cloudy—lt. wind throughout the day. Ev. Overcast—slight rain.
T 26	29.806	29.800	57.9	29.816	29.810	60.7	52	06.0	56.2	62.8	51.2	61.6	.119	S	Cloudy—brisk wind throughout the day. Ev. Fine and moonlight.
F 27	29.980	29.974	63.6	29.984	29.976	63.0	57	06.4	61.3	65.7	52.0	63.8	.102	S	Cloudy—light wind throughout the day. Evening, Overcast.
S 28	30.050	30.042	60.7	30.076	30.068	62.6	54	05.2	57.5	64.8	54.0	68.4	.066	NW	Cloudy—light wind throughout the day—rain in the night. Evening, Fine and starlight.
☉ 29	30.184	30.176	75.8	30.092	30.086	64.5	55	08.0	61.8	66.5	51.2	78.3	.126	S	Fine and cloudless—light wind—rain in the night. Evening, Fine and starlight.
M 30	30.010	30.002	66.3	30.026	30.018	65.0	53	08.6	62.3	68.8	53.7	69.6		SSW	Fine—light clouds and wind throughout the day. Ev. Overcast.
T 31	30.192	30.184	75.4	30.174	30.166	66.0	56	07.9	60.7	67.2	53.7	73.0		S	Fine—light clouds & wind throughout the day. Ev. Fine & starlight.
MEAN.	29.958	29.951	63.6	29.930	29.922	60.1	50	06.0	55.5	61.0	48.8	64.9	Sum. 1.934		Mean Barometer corrected .... 9 A.M. 3 P.M. F. 29.868 .. 29.850 C. 29.860 .. 29.841
W 1	30.284	30.278	76.0	30.206	30.198	66.8	54	08.6	64.5	71.4	53.2	81.5	.019	S	Fine—light clouds and wind throughout the day. Rain during the night. Evening, Fine and starlight.
T 2	30.250	30.242	66.2	30.278	30.270	67.2	60	07.2	64.5	68.8	60.0	72.3		NW	A.M. Cloudy—light wind. P.M. Fine—light clouds and wind. Ev. Fine and starlight.
F 3	30.368	30.360	77.3	30.268	30.260	67.5	55	08.4	63.3	71.7	53.0	76.5		E	Fine—nearly cloudless throughout the day. Ev. Fine and starlight.
S 4	30.168	30.160	72.9	30.084	30.076	68.6	54	10.7	66.3	75.5	54.0	77.5		NW	A.M. Fine—nearly cloudless. P.M. Fine—lt. clouds. Ev. Cloudy.
☉ 5	30.018	30.010	69.4	29.934	29.928	71.0	58	09.0	66.4	76.0	59.4	76.0		S	Cloudy—light wind throughout the day. Evening, The same.
M 6	30.002	29.996	71.6	30.042	30.034	70.7	61	10.0	68.5	73.0	57.4	77.0		N	A.M. Fine—light clouds and wind. P.M. Fine and cloudless—light wind. Evening, Fine and starlight.
T 7	30.264	30.256	79.0	30.248	30.240	70.8	55	10.0	66.7	71.7	56.4	76.0		E	Fine—lt. clouds and wind throughout the day. Ev. Fine & starlight.
◐ W 8	30.324	30.318	77.7	30.268	30.260	72.0	63	07.3	66.8	72.2	55.3	72.7		NW	Cloudy—light wind throughout the day. Ev. Fine and starlight.
T 9	30.314	30.308	82.7	30.218	30.210	71.5	60	07.3	63.4	73.2	54.0	78.3		N	A.M. Fine—light clouds and wind. P.M. Fine and cloudless. Evening, Fine and starlight.
F 10	30.182	30.174	81.3	30.124	32.116	71.0	61	10.1	66.3	76.5	52.7	74.2		NE	Fine and cloudless—stiff breeze throughout the day. Evening, Fine and starlight.
S 11	30.254	30.248	82.7	30.226	30.218	72.0	62	06.7	65.2	80.3	53.8	77.4		N	Fine & cloudless—lt. breeze throughout the day. Ev. Fine & starlight.
☉ 12	30.362	30.354	80.5	30.334	30.328	73.0	66	07.0	68.3	80.5	56.6	82.2		N	Fine—nearly cloudless—light wind throughout the day. Evening, Fine and starlight.
JUNE M 13	30.358	30.350	75.7	30.264	30.256	73.3	61	07.6	64.8	78.3	58.2	82.4		N	Fine and cloudless—light breeze throughout the day. Evening, early part, cloudy, after, fine and starlight.
T 14	30.168	30.160	74.9	30.098	30.090	74.0	63	07.9	72.3	80.5	62.6	79.7		E	A.M. Cloudy—light breeze. P.M. Fine—light clouds and breeze. Evening, Cloudy—light shower.
W 15	30.110	30.102	75.3	30.108	30.100	73.0	63	08.0	66.3	68.3	59.0	82.4	.033	NW	A.M. Cloudy—lt. breeze. P.M. Fine—lt. clds. & breeze. Ev. Cloudy.
T 16	30.062	30.056	79.3	30.042	30.034	72.3	58	09.7	66.3	70.7	57.2	79.2		NW	A.M. Cloudy—stiff breeze. P.M. Fine—light clouds aud breeze. Evening, Overcast.
F 17	30.132	30.124	71.6	30.130	30.122	69.6	58	08.1	64.0	64.3	56.7	72.7		S	A.M. Overcast. P.M. Dark broken clouds. Evening, Cloudy.
S 18	30.086	30.078	65.4	30.000	29.992	66.5	56	05.7	59.5	60.0	54.4	68.8		E	A.M. Overcast—brisk wind. P.M. The like with lt. rain. Ev. Cldy.
☉ 19	29.806	29.798	64.7	29.730	29.724	67.0	58	05.7	60.3	68.2	54.6	66.8	.069	S	A.M. Overcast—heavy rain. P.M. Dark heavy clouds—distant thunder. Ev. Cloudy, with showers, and thunder.
M 20	29.788	29.782	66.2	29.746	29.740	68.7	60	07.7	66.2	69.7	56.2	69.7	.263	SE	Cloudy—light breeze throughout the day. Evening, The same.
T 21	29.696	29.690	71.0	29.674	29.666	69.3	58	07.3	65.8	68.7	59.3	76.3	.077	SSE	Cloudy—light breeze with occasional light rain throughout the day. Evening, Cloudy.
○ W 22	29.824	29.818	75.6	29.772	29.766	70.0	59	08.8	65.7	71.0	56.8	83.6	.027	W	A.M. Fine—light clouds and breeze. P.M. Cloudy—brisk wind. Evening, Cloudy—light showers.
T 23	29.896	29.890	77.4	29.882	29.874	69.3	58	08.1	62.5	68.7	53.0	78.7	.041	W	A.M. Fine—lt. clouds & breeze. P.M. Cldy.—stiff breeze. Ev. The [same.
F 24	29.732	29.724	66.3	29.730	29.722	69.6	61	05.8	62.3	68.8	61.0	71.6	.033	S	Overcast—light brisk wind, with occasional light rain throughout the day. Evening, Cloudy.
S 25	29.864	29.856	68.7	29.746	29.738	68.0	58	07.8	64.7	64.7	57.3	71.3	.033	S	A.M. Overcast—stiff breeze. P.M. Overcast—stiff breeze—light rain. Evening, The same.
☉ 26	29.748	29.744	78.6	29.840	29.834	68.0	52	09.1	62.0	67.5	57.0	74.0	.019	NW var.	Fine—lt. clds.—stiff breeze throughout the day. Ev. Fine & starlight.
M 27	30.228	30.222	71.2	30.278	30.270	69.3	57	09 7	63.3	69.3	53.3	78.3	.016	NW	A.M. Cloudy—brisk wind. P.M. Fine—light clouds—brisk wind. Evening, Fine and starlight.
T 28	30.344	30.340	81.3	30.252	30.244	70.0	55	09.3	65.3	75.5	53.0	83.6		W	A.M. Fine & cloudless—lt. breeze. P.M. Fine—lt. clds. Ev. Fine & [starlight.
W 29	30.154	30.148	79.7	30.078	30.070	70.0	61	08.0	66.5	75.4	57.8	79.8		W	A.M. Fine—light clouds and breeze. P.M. Fine—nearly cloudless—light breeze. Ev. Fine and starlight—light clouds.
T 30	30.006	30.000	72.3	29.876	29.868	71.0	60	06.1	64.2	67.3	57.0	77.3		N	A.M. Overcast—light rain and wind. P.M. Cloudy, with occasional light rain. Evening, Overcast—light rain, with lightning.
MEAN.	30.093	30.086	74.4	30.049	30.042	70.0	59	08.1	65.1	71.6	58.3	76.6	Sum. .630		Mean Barometer corrected .... 9 A.M. 3 P.M. F. 29.974 .. 29.942 C. 29.966 .. 29.934